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THE MILLER CREEK-NEWMAN RIDGE STUDY

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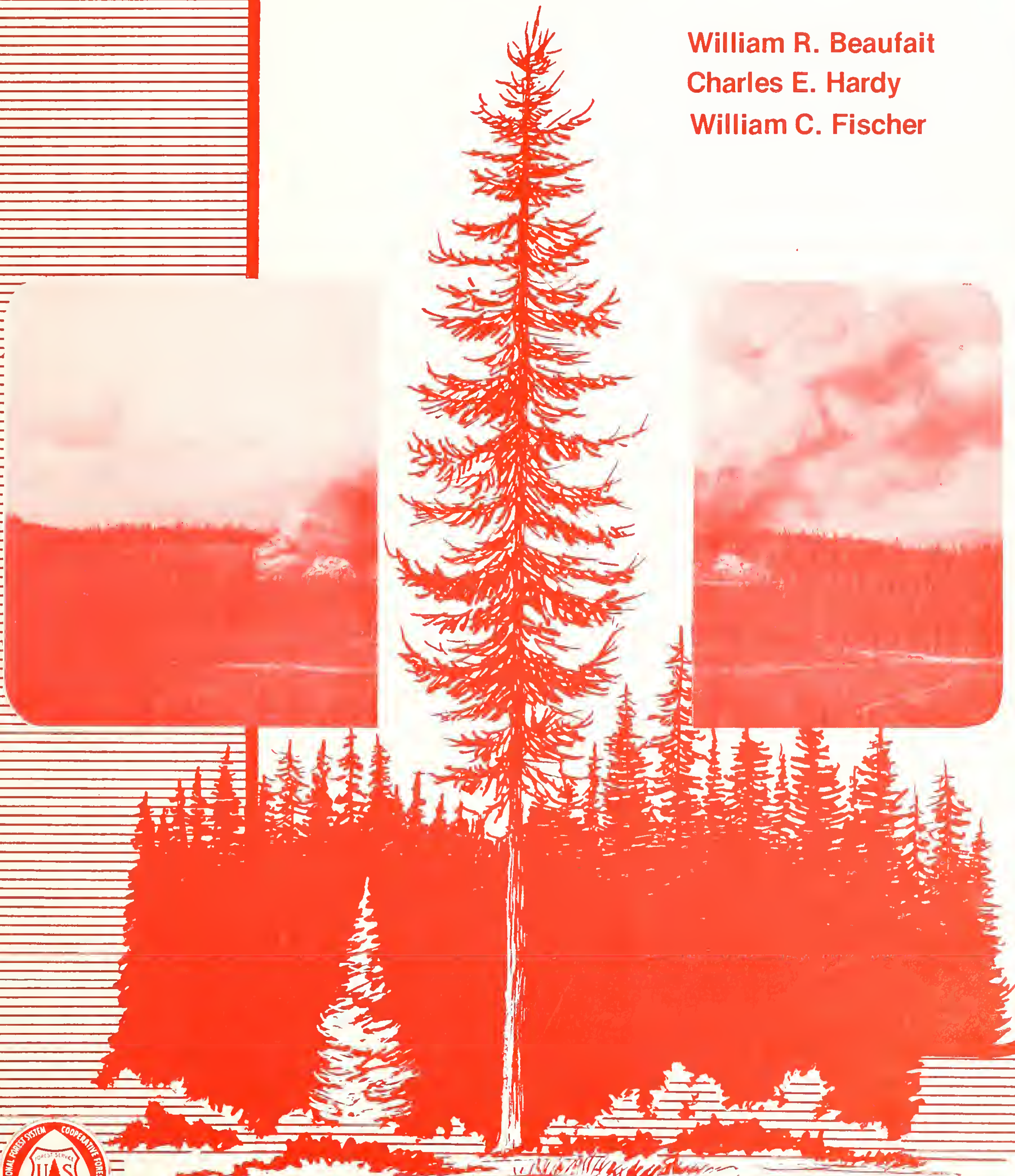

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THE AUTHORS

WILLIAM R. BEAUFAIT was graduated from Wayne State University (1949) and the University of Minnesota (1952), and holds a Ph. D. degree from the University of Michigan (1960). He spent 4 years in soils and silvicultural research in hardwoods for the Southern Forest Experiment Station, and 2 years studying the role of fire in the regeneration of northern conifers at Michigan Technological University. Dr. Beaufait was on the staff of the Northern Forest Fire Laboratory between 1962 and 1972 as a specialist in fire use. He is author of more than 30 published articles and reports. During this period he contributed to the scientific use of fire for resource management and toward understanding the role of fire in the environment. He was the principal scientist during the entire life of the study reported herein. In 1972 he became Regional Silviculturist for the Forest Service's Northern Region.

CHARLES E. HARDY was leader of the Fire Management Research Work Unit at the Northern Forest Fire Laboratory within which the study was conducted and also served on the study steering committee. He received a B. S. F. at the University of Montana in 1939 and an M. F. at the University of Michigan in 1949. Following naval duty in World War II, he served on the staffs of two National Forests and the Division of Fire Control in Region 1. In 1951 he joined the Division of Fire Research in Missoula where he conducted studies relating to fire-danger rating, prescribed fire, fire behavior, Alaskan fire problems, and fire-retarding chemicals. He has authored 18 published articles and reports. Mr. Hardy was leader of the Fire Technology Research work unit at the time of his retirement in December 1973.

WILLIAM C. FISCHER is Project Leader for the Fire Effects and Applications Research Work Unit at the Northern Forest Fire Laboratory. He conducted fuel moisture studies at Miller Creek and Newman Ridge and was responsible for collecting weather data and evaluating fire danger for the study area. Mr. Fischer holds B.S. and B.S.F. degrees from the University of Michigan.

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Supervisors, staff officers, and rangers on the Lolo, Flathead, and Coeur d'Alene National Forests facilitated sale preparation and a rigorous harvest and treatment schedule on the study area. Ray L. Managhan and Gary L. Cain deserve special recognition for their dedcated efforts as sale administrators and burning bosses.

Cooperating scientists and technicians who participated in the study were:

Donald F. Adams, Washington State University, Air Quality Research

Curtis H. Halvorson, USDI, Bureau of Sport Fisheries and Wildlife, Wildlife Ecology Research

Norbert V. DeByle and Paul E. Packer, Watershed Management Research (INT)

Raymond C. Shearer and Robert D. Pfister, Silviculture Research (INT)

L. Jack Lyon and Peter F. Stickney, Wildlife Habitat Research (INT)

Rodney A. Norum (INT) had major responsibility for collecting and organizing much of the fire research data and provided valuable technical advice during preparation of the study report.

Patrick F. Hartless, project forestry technician, was responsible for unit layout, fuel inventory, weather measurement, and plot measurement.

Michael A. Marsden, statistician, and Roger A. McCluskey, programer, Intermountain Station, were responsible for data reduction and analysis.

ABSTRACT

Seventy-three clearcuts in western larch/Douglas-fir forests of western Montana were broadcast burned over a wide range of environmental conditions for the purpose of quantifying fire characteristics and burn accomplishment. The moisture content of the upper duff, and the National Fire-Danger Rating System Buildup Index (1964) were found to be important predictors of both the heat pulse to the site and the amount of duff removed by the fire. The same two variables along with the preburn weight of 1 to 10 cm fuels were the best predictors of the amount of fuel consumed by the fire. Associated studies are yielding information on tree regeneration, vegetal development, small mammal population dynamics, nutrient cycling, water quality, runoff and soil erosion, smoke dispersal, and convection column height--all related to varying fire characteristics and burn accomplishment.

CONTENTS

INTRODUCTION

As a land management tool, prescribed fire is so widely accepted and so universally practiced as to merit definition in *Forestry Terminology* (Society of American Foresters 1958): "The application of fire to land under such conditions of weather, soil moisture, time of day, and other factors as presumably will result in the intensity of heat and spread required to accomplish specific silvicultural, wildlife, grazing, or fire-hazard reduction purposes."

The use of prescribed fire for hazard reduction and seedbed preparation is a well-established management technique in northern Rocky Mountain forests (Olson and Fahnestock 1955; Roe and others 1971). Broadcast burning following clearcutting is an especially popular technique because, when successfully executed, both the fuel reduction and site preparation jobs are accomplished simultaneously.

Based on interviews with foresters throughout the Intermountain West, Beaufait (1966b) characterized a successful broadcast burn as one that: (1) consumed the duff to the extent of exposing mineral soil on 50 percent or more of the area burned, and (2) consumed all woody material up to about 6 inches in diameter.

Prescribed broadcast burns have not always accomplished these objectives. As a tool for preparing sites for future crops, prescribed fire was found to be producing erratic results in many areas of the Intermountain West, (e.g., not enough seedlings in spruce forest types, too many in larch and lodgepole). Wikstrom and Alley (1967) found a large unexplained variation in slash disposal and burning costs across the Northern Region of the Forest Service. It became important to relate such variation to silvicultural practices. The practice of clearcutting coupled with the short duration of the traditional fall burning period resulted in an increasing backlog of acres requiring postlogging treatment.

Probably the most important reason for prescribed burning failures is the variable nature of fire itself. Fire can burn over any given area in an infinite number of ways. Intensity depends on fuel volume and moisture content as well as on environmental conditions. Thus, fire is not a single treatment but rather a number of possible treatments. To be successful, the prescription and execution of a fire must be specific to a fuel bed, its moisture condition, and at least one well-defined management objective.

Prescribed fires are often scheduled during safe burning conditions for the convenience of the organization responsible for the burning. Concern is often centered on the *fact* of treatment rather than on the *quality* of treatment. Furthermore, emphasis is often placed on burning to reduce subsequent wildfire hazard, seedbed preparation being an expected side benefit. Although the wildfire hazard may be satisfactorily reduced by burning only the fine fuels, site preparation may not occur unless the heavier fuels are also burned.

The need to improve the quality of prescribed burning accomplishment was recognized by land managers and research scientists alike. Consequently, the Northern Region and the Intermountain Forest and Range Experiment Station of the USDA Forest Service jointly supported a study of prescribed fire and its use in forest management.

The principal objective of this study was to develop criteria by which prescribed fires can be scheduled to best meet site preparation, hazard reduction, and other forest land management objectives. The study was limited to broadcast burning of logging residues on clearcuts in the western larch/interior Douglas-fir type in western Montana.

Specific fire research objectives were:

1. Correlate a wide range of fuel and weather conditions with the amount of duff reduction and mineral soil exposure.

2. Identify and adapt (if necessary) indices of the National Fire-Danger Rating System (USDA Forest Service 1964) that characterize fuel and weather conditions that produce a burn of a specific quality.

3. Predict prescribed fire smoke column height from fuel conditions and environmental factors.

4. Provide a basic design and field layout for ancillary studies by cooperating research groups.

Ancillary Studies

One major failing of most existing fire effects literature is in adequate quantification of the fires involved. Often, fire intensity is simply characterized as being "high" or "low" based on the investigator's experience. The study design provided on unparalleled opportunity to correlate fire effects with quantified fires conducted over a wide range of fuel and environmental conditions.

Silviculture Research

Silviculturists investigated the effects of broadcast burning in larch-fir clearcuts on regeneration of western larch, Engelmann spruce, and Douglas-fir. The studies dealt with: (1) seed losses, germination, root development, and seedling survival; (2) planting stock survival and early development, and (3) the length of time the burned sites remain receptive to seeding and planting.

Watershed Research

Runoff and soil erosion studies were established (1) to determine vegetative characteristics, soil properties, topographic factors, and burning intensities that affect overland flow and erosion; and (2) to describe the overland flow and erosional behavior of larch/Douglas-fir/spruce forest land that can be predicted by forest managers. Thus, burning conditions could be identified that were best suited for site preparation and fire hazard reduction (Packer 1971; DeByle and Packer 1972).

Watershed specialists also studied the effects of burning on water quality and soil chemistry. Changes in soil fertility, quality of surface runoff water, and quality of water percolating through the soil mantle were described. Other soil properties studied were bulk density, porosity, organic matter, wettability, and nutrient content (DeByle and Packer 1972; DeByle 1973).

Wildlife Research

Wildlife habitat study plots were installed throughout the study area to describe vegetative response and to relate vegetal recovery to fire intensity.

A small mammal population study had the following objectives: (1) to measure small mammal species composition and relative abundance on uncut forest blocks, (2) to measure changes in species composition and relative abundance following prescribed burning of clearcut blocks, and (3) to describe small mammal succession after clearcutting and broadcast burning.

Air Quality Research

A three-phase field, laboratory, and theoretical study of air pollution potential was designed to identify weather conditions that would minimize pollution from prescribed fires. The study involves: (1) quantitatively and qualitatively defining the range of solid and gaseous combustion products produced by burning larch-fir slash, and (2) relating field-measured pollutants with those predicted through mechanical models of atmospheric diffusion phenomena (Adams and Koppe 1969; Flaherty 1967).

Publication of Results

This report does not attempt to document results of the ancillary studies. Much has already been published and more is forthcoming (appendix A). Smoke column height prediction at Miller Creek has been reported separately (Norum 1970, 1974). Fuel inventory techniques have also been reported in a separate publication (Beaufait and others 1974). Brown (1970) has provided a detailed report on the vertical distribution of fuel and Albini (1975) has reported on his attempt to relate heat release per unit area and duff reduction. The main purpose of this publication is to provide a project record of the Miller Creek-Newman Ridge Study. A summary report will present an integrated discussion of all that was learned during the study and will provide fire management guidelines for prescribed broadcast burning in larch-fir clearcuts.

HISTORY OF PRESCRIBED BURNING

Prescribed burning for silvicultural purposes has been a part of American forestry since the first real attempts at intensive management. Chapman (1926, 1942) is considered by many to have made the first serious application of prescribed fire in his treatments of the longleaf and loblolly pine types of Arkansas and Louisiana. Beneficial results in the form of seedbed preparation and the reduction of vegetative competition in loblolly stands were matched by the effectiveness of this tool in controlling brown spot needle blight and stimulating release from the grass stage of longleaf pine (Siggers 1934).

McCulley (1950) and Lotti (1956) expanded the use of prescribed fire in southern pine management to the southeastern tier of states and promoted the hazard reduction virtues of this technique. Thereafter, Ferguson and Stephenson (1954) found that prescribed burning in eastern Texas increased pine seedling survival and reduction competition from less valuable hardwoods.

Meanwhile, in New Jersey, Little and Somes (1949) and Little (1953) sought to perpetuate pitch, shortleaf, and loblolly pine stands in the face of encroachment by more tolerant hardwoods. By this time it had become apparent that prescribed fire was a powerful weapon with which to engage the forces of plant succession to achieve land management objectives.

In the Lake States, fire use for game habitat improvement was explored by Smith (1947), and is presently an accepted practice. Recent development of prescribed burning techniques for jack pine reproduction (Williams 1958; Chrosciewicz 1959; Beaufait 1960a) has found application in Canadian and U.S. stands of this often serotinous-coned species.

Studies of fire use for the improvement of semiarid rangelands began during the late twenties in Colorado (Hanson 1929) and southern Idaho (Pechanec and others 1954), although fire had already been employed for many years by ranchers throughout the West.

California brush ranges have been the subject of much study and controversy with regard to fire use since early in the century. Shantz (1947) summarized the past human and ecological consequences of prescribed burning in the chaparral types. Type conversion, hazard reduction, and game habitat improvement have been effected by the intelligent use of fire in California. Many of the burning techniques which have been developed as part of these programs are applicable in the Intermountain West.

Ponderosa pine stands have been burned to reduce fire hazard and vegetative competition and to prepare sites for reforestation. Beginning with the work of Pearson (1950) in the Southwest, and by Weaver (1955) in northeastern Washington, prescribed fire had passed preliminary tests as a silvicultural tool, but as yet had not been put into general practice (LeBarron 1957). Lindenmuth's (1960) survey of burning in ponderosa pine in Arizona stresses the need for more reliable means of controlling fire intensities to achieve desired objectives of fuel reduction and thinning of dense stands. Meanwhile, Morris and Mowat (1958) continued to study the aftereffects of thinning fires in Washington ponderosa pine stands, with concentration on burning procedures.

Broadcast burning of logging slash for hazard reduction and planting site preparation began as early as 1910 in the western white pine type of Idaho (LeBarron 1957). The scattered references to such practices contained no data on weather or fuel conditions until Davis and Klehm (1939) published guides for burning clearcut stands of white pine. In 1945, Lyman, concerned by the logging slash in Montana and northern Idaho, recommended greater use of fire in the treatment of slash and for converting overstocked or low quality stands of lodgepole pine and western hemlock to more valuable species.

During this time, timber management researchers in the Northern Rockies were looking to fire as a multiple-purpose tool in the treatment of problem stands. Wellner's (1946) suggestion to control *Ribes* through successive burns in cutover white pine stands has resulted in considerable burning for white pine regeneration and sanitation. Boe (1952) successfully tested fire as a regeneration method for lodgepole pine.

More recently, attention has been focused on the nature of fuels and fire itself. Measurements of slash fuels and the behavior of slash fires made by Olson and Fahnestock (1955), Fahnestock (1960), and Fahnestock and Dieterich (1962) provided a basis for quantifying potential energy sources in the use of fire for silvicultural and other land management purposes. This research compared flame height, rate of spread, and heat radiation on 0.01-acre plots with fuel loadings of 7.5, 20.0, and 32.5 tons per acre. Other forest fire researchers began characterizing natural forest fuel beds by the amount of work accomplished by prescribed fires. Using Byram's (1959) equations for energy release rate, Van Wagner (1965) compared the effects of burning 1/4-acre plots in red and eastern white pine stands at four levels of fire hazard. The latter expressed head fire intensity of each fire in a range of 20 to 370 Btu's per-second-per-foot of front and applied these data to the tree crown and stem damage, seedbed preparation, and subsequent regeneration. Van Wagner found that as fire intensity increased, both mineral soil exposure and seedling success improved. Similar results were reported by Buckman (1962, 1964) from his studies of fire's effects on hazel stems, and by Beaufait's (1960b, 1962) work with jack pine regeneration after slash burning.

Burning logging slash in the Pacific Northwest Douglas-fir region "after the duff had been soaked by rain and as soon after rain as fine fuels were dry enough to carry fire" consumed most fine fuel, left nearly all logs, and severely burned less than 6 percent of the soil surface (Morris 1970).

Earlier, Morris (1966) studied the relationship between moisture content of half-inch fuel moisture sticks and safe but effective broadcast slash burning. For coastal Douglas-fir sites, he found the significant factors to be moisture content of fuel sticks, aspect of slope, and moist/dry appearance of the lower layer of duff.

More recently, laboratory studies of fire behavior in forest fuels have laid a foundation for characterizing fires under natural conditions. Building upon the work of Thomas (1958, 1963), Rothermel and Anderson (1966) modeled mat-type fuel beds and stressed the importance of equivalent unit energy release rate in describing fire intensity and behavior.

Between 1963 and 1965, a series of 2- to 4-acre areas were inventoried and broadcast burned in Douglas-fir slash on the University of Montana's Lubrecht Experimental Forest. These tests provided: (1) a quantitative comparison of site and early vegetative succession after replicated fires in two spring and two autumn seasons, and (2) successful instrumentation for evaluating burn quality, fire intensity and spread, fuel volume and moisture content, and ignition and control methods (Steele 1964; Steele and Beaufait 1969).

A survey of prescribed burning practices in the Intermountain West identified problems encountered by forest managers. The study showed the necessity for ". . . exchange of knowledge between fire and control personnel and other specialists who use fire . . ." and the need for ". . . burning during spring and certain summer periods..." to reduce backlogs, increase acreage treated, and attain more precisely the management objectives of burning (Beaufait 1966b).

Also, in 1966, slash-fuel inventory techniques, fire characterization methods, and control methods were tested and refined in a full-scale (30-acre) broadcast burn during relatively severe August conditions on the Coram Experimental Forest.[1]

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[1]Beaufait. William R. Fuels inventory for prescribed fire. (Paper presented at annual meeting of Northwest Science Association, Forestry Section, Pullman, Washington, April 1967).

PROJECT RECORD— MILLER CREEK-NEWMAN RIDGE STUDY

Study Design

The primary fire research task was to relate burn accomplishment to fuel quantity, fuel moisture, and atmospheric situations. This problem lends itself to solution by regression analysis where a dependent variable (Y = burn accomplishment) is expressed as some function of a number of independent variables (X = fuel moisture, etc.). Inventory of fuels both before and after treatment on 7,000 points, stand examination data from 324 points, fire evaluation data from 3,600 points, weather information on 450 days, and miscellaneous inputs from subsampling problems generated over 20,000 original data cards during the course of this study. Grosenbaugh's (1967) "REX" programs were used for screening and regression analysis. A list of variables examined in regression equations and a list of all programs used and their sources are on file at the Northern Forest Fire Laboratory.

The study was designed to be as orthogonal as possible. The original plan specified: (1) an equal number of treatments in, (2) similar fuels on each of four cardinal exposures in, (3) spring, summer, and autumn, (4) over a period of 3 years, (5) on two separate experimental blocks. Complete orthogonality was not, in fact achieved. Units with heavier fuel loadings tended to be burned under conditions of higher fuel moisture than units with lighter loadings. More than anything else, this reflects a compromise between rigid adherence to experimental design and the "real world" considerations of the fire manager. A second factor affecting orthogonality was the occurrence of wildfires that burned over several units. In 1967, a wildfire at Miller Creek unbalanced the study design by burning four of six units on the same exposure.

Study Area Description

Location and Unit Layout

The study area (fig. 1) consisted of a 641-acre block located at the Miller Creek and Martin Creek Drainages of the Flathead National Forest (48°31' N. Latitude, 114°45' W. Longitude) and a 526-acre block lying on Newman Ridge between Two Mile Creek and Ward Creek on the Lolo National Forest (lat. 47°15' N., long. 115°20' W.).

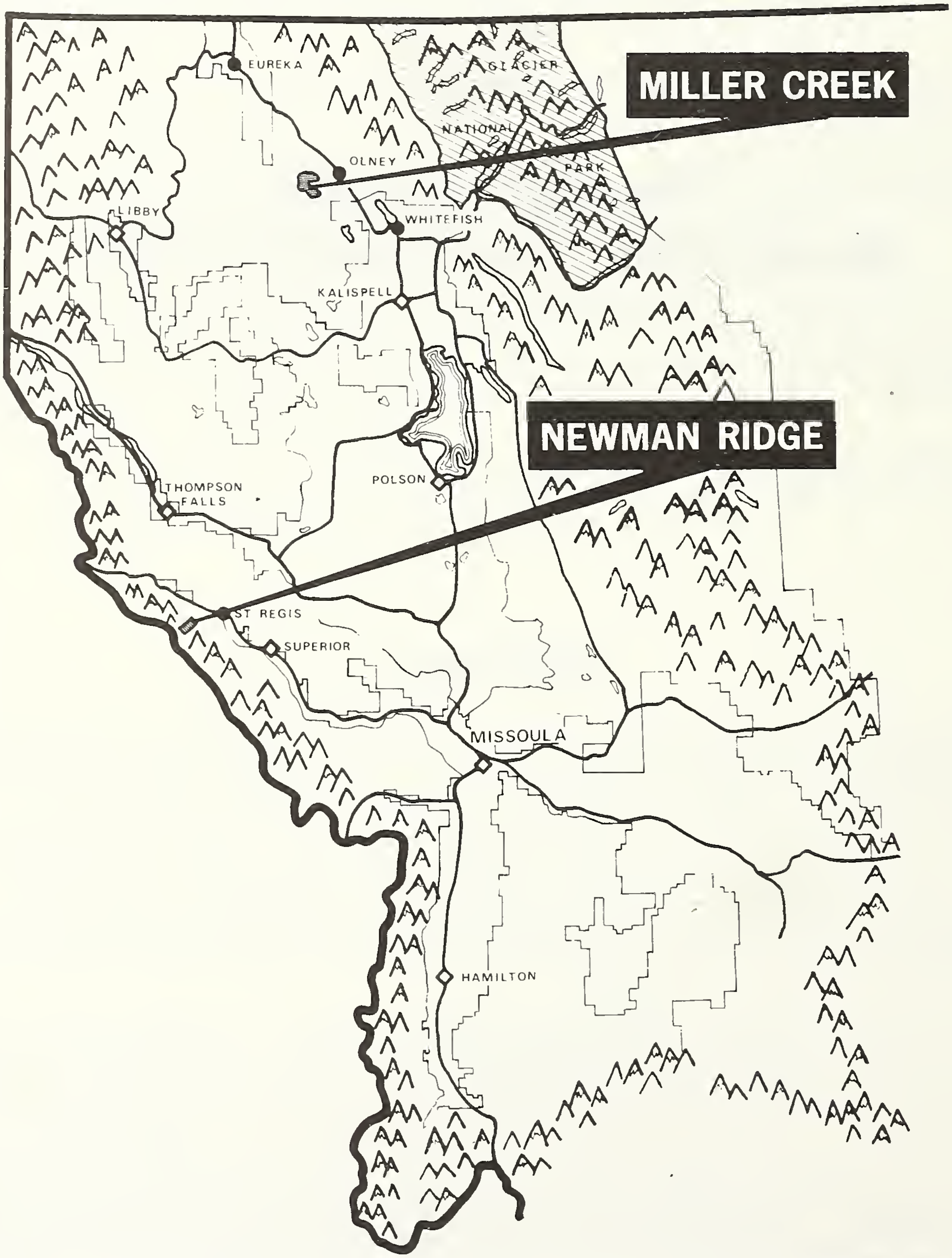

Figure 1.--Study sites on the Flathead and Lolo National Forests in western Montana.

A combined total of 76 treatment units were located on both blocks, with an equal number facing each cardinal direction. Units were first planned on aerial photographs to conform to natural topographic boundaries, with slopes and exposures as uniform as possible. The 60 units at Miller Creek (fig. 2) were square, 10 chains on a side, and included one 2-1/2-acre sample plot surrounded by a 2-1/2-chain-wide isolation strip. The 16 Newman Ridge units (fig. 3) ranged in size from 21 to 58 acres and contained three 2-1/2-acre sample plots each. Sampling points were established in each 2-1/2-acre sample plot as illustrated in figure 4.

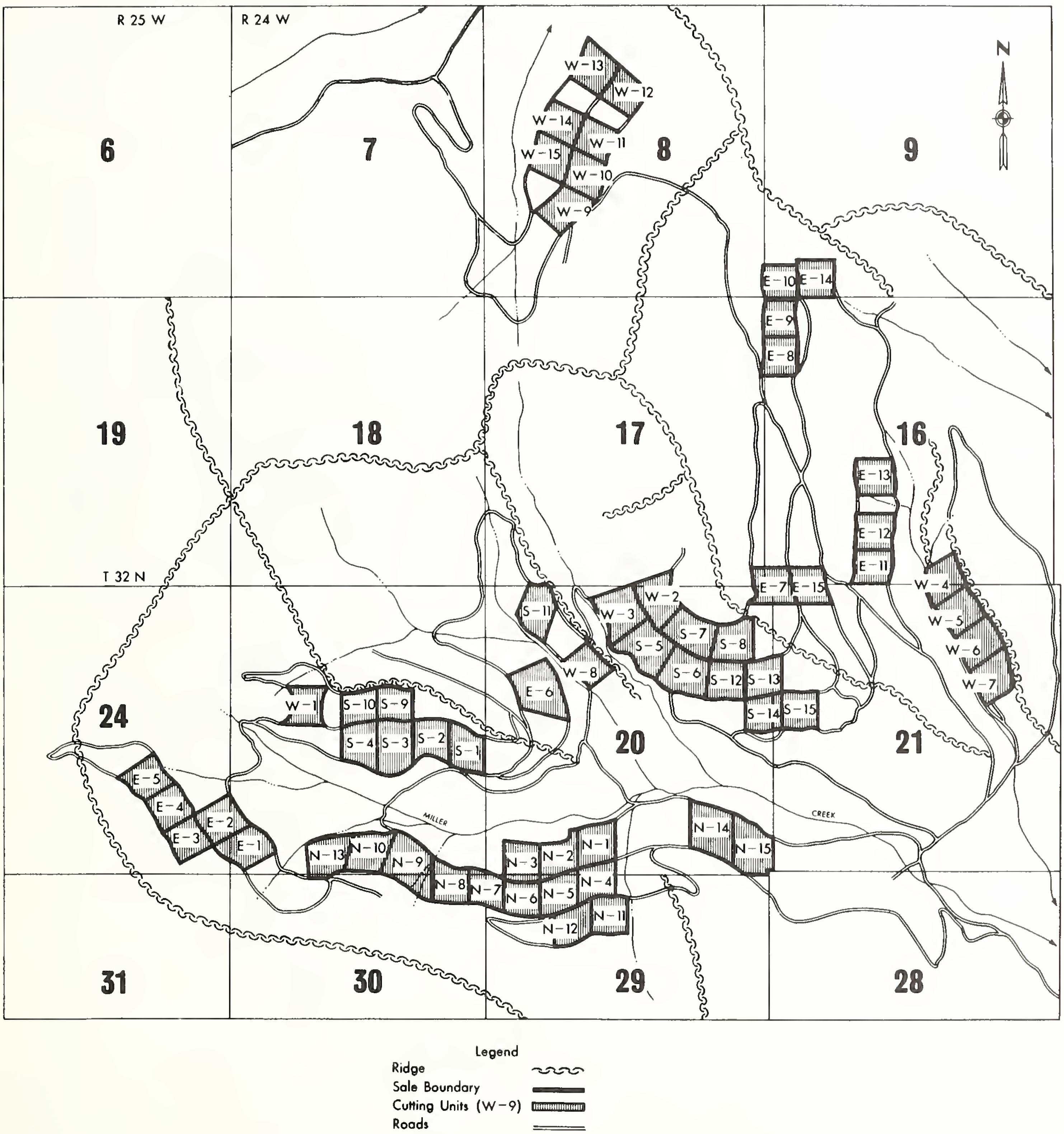

Figure 2.--Miller Creek block unit layout.

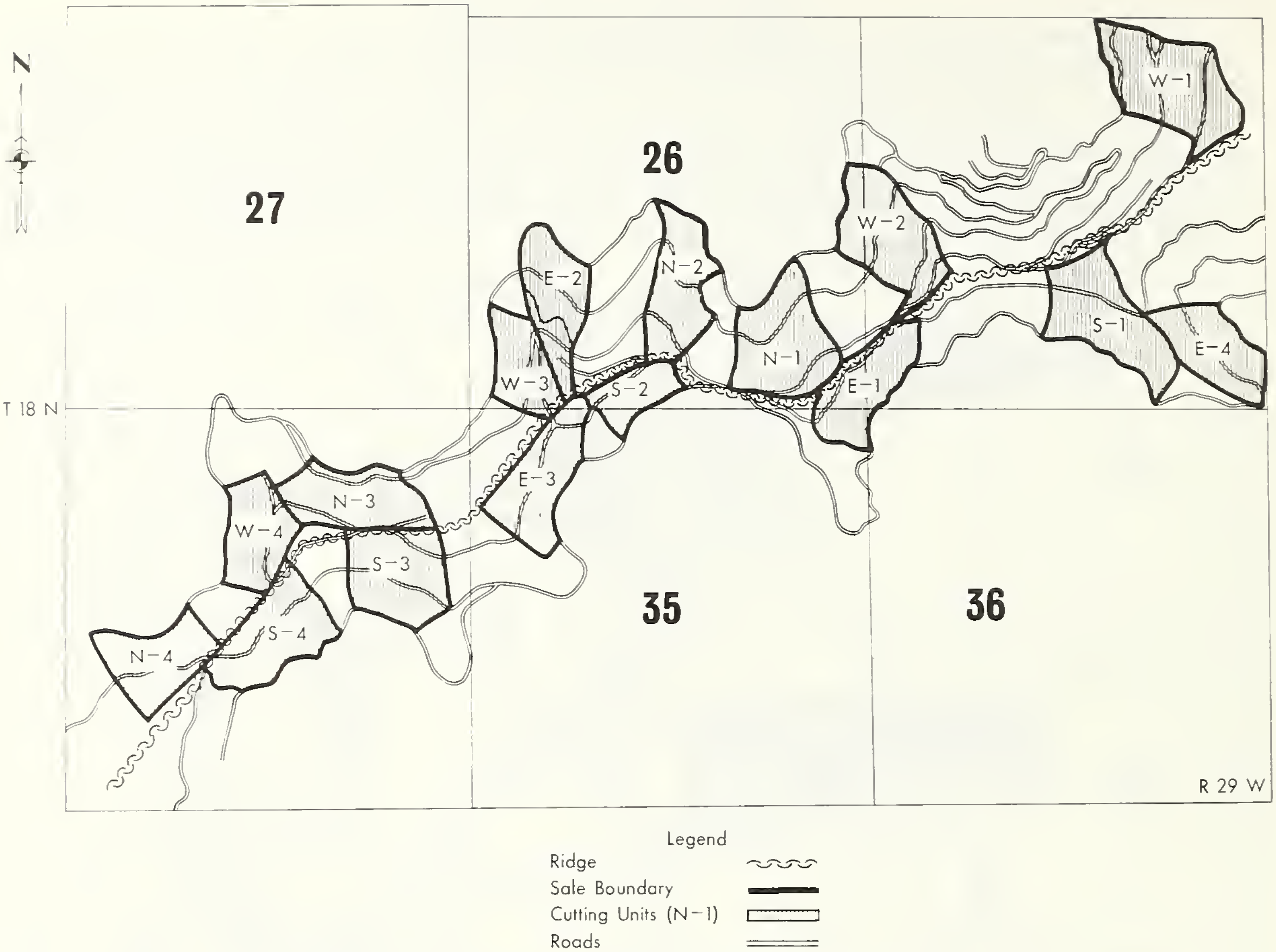

Figure 3.--Newman Ridge block unit layout

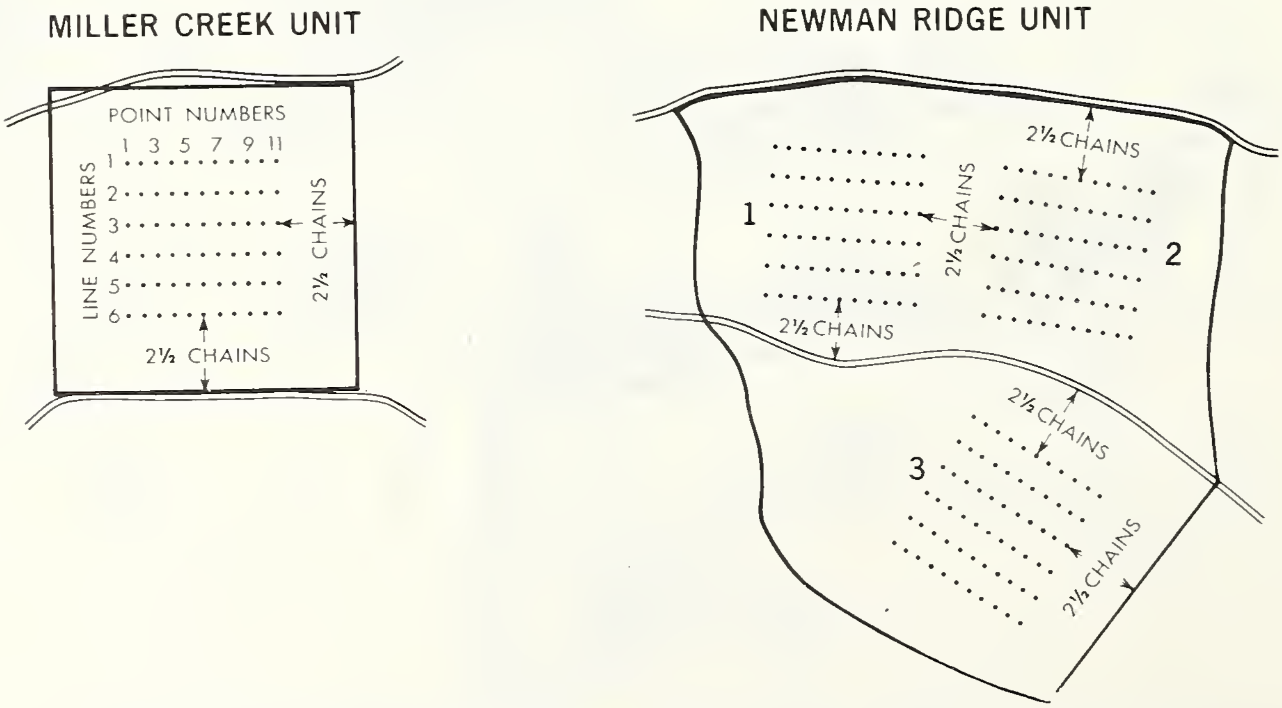

Figure 4.--Plot layout and sampling point locations on typical units.

Topography, Soils, and Climate

DeByle and Packer (1972), have described the topography, soils, and climate of the study area:

> The elevation at Miller Creek ranges from 4,200 to 5,000 feet. Slopes average 24 percent and range from 9 to 35 percent. Soils have developed in glacial till from the argillites and quartzites of the Wallace (Belt) formation and are mantled with a thin layer of loess. They belong to the Sherlock soil series and, for the most part, are Andic Cryoboralfs having an unincorporated surface organic horizon from 1 to 3 inches thick. The surface 1/2 to 1 inch of mineral soil is silt loam of single-grain structure (30 percent sand, 56 percent silt, 14 percent clay). This overlies a foot of gravelly loam with a weak blocky structure, beneath which is very stony loam to a depth of at least 6 feet.
>
> The Newman Ridge study area is slightly higher (elevations range from 4,400 to 5,400 feet) and much steeper (mean slope of 55 percent, ranging from 44 to 76 percent) than is Miller Creek. The soils have developed in place or in colluvium from argillites and quartzites of the Belt formation. The surficial loess deposit at Miller Creek is 1/2 to 2-1/2 inches thick; on Newman Ridge it is 2 to 3 inches thick. Ash from the Mt. Mazama and Glacier Peak volcanic eruptions occurs in this loess (Fryxell 1965); the remainder of the deposit probably comes from the Palouse region in eastern Washington. The texture of the surface 2 inches of soil on Newman Ridge is silt loam (29 percent sand, 58 percent silt, and 13 percent clay). These soils belong to the Craddock series and classify as Andic Cryochrepts.
>
> Miller Creek and Newman Ridge characteristically have long, cool and wet winters and short, dry summers. Annual precipitation averages about 25 inches at Miller Creek and nearly 40 inches at Newman Ridge; approximately two-thirds falls as snow. Although high-intensity summer rainstorms occasionally occur, most summer rain falls at low intensities from Pacific maritime frontal systems. The most rainfall comes during April, May, and June, the months when snowmelt runoff is greatest.
>
> Both Miller Creek and Newman Ridge can be classed as humid watershed lands, which yield more than 10 inches of stream flow annually, nearly all yearlong seepage flow (Packer 1959). When plant cover is sufficient, only a small part of the annual precipitation becomes overland flow. Most of it contributes to seepage flow or is stored in the soil mantle and thus reduces soil moisture deficits created by evapotranspiration.

Forest Cover and Habitat Types

Vegetation was classified according to forest cover type (Society of American Foresters 1967) and habitat type (Daubenmire 1952).

Cover types identified were: larch/Douglas-fir, grand fir/larch/Douglas-fir, ponderosa pine/larch/Douglas-fir, lodgepole pine, and Engelmann spruce/subalpine fir.

The larch/Douglas-fir type covered well over 50 percent of the study area. With typical variation due to exposure, Miller Creek timber volumes were evenly divided among western larch, interior Douglas-fir, and Engelmann spruce. Newman Ridge, being a bit cooler and drier, produced little spruce, but showed a greater variety of species, including some ponderosa pine and western white pine. Lodgepole pine and true firs had significant volumes in both blocks.

Figure 5.--Habitat types, Miller Creek.

Average age of Miller Creek stands was 200 to 250 years; those at Newman Ridge averaged 180 to 200 years. Table 1 summarizes the amount of commercial timber harvested from the study area.

Habitat typing on the study area represents an early extension of this technique into western Montana. The habitat type maps in figures 5 and 6 do not reflect recent refinements.[2]

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[2]Pfister, Robert D., Bernard L. Kovalchik, Stephen F. Arno, and Richard C. Presby. Forest habitat types of Montana, May 1974. USDA For. Serv., Intermt. For. and Range Exp. Stn. and North. Reg.

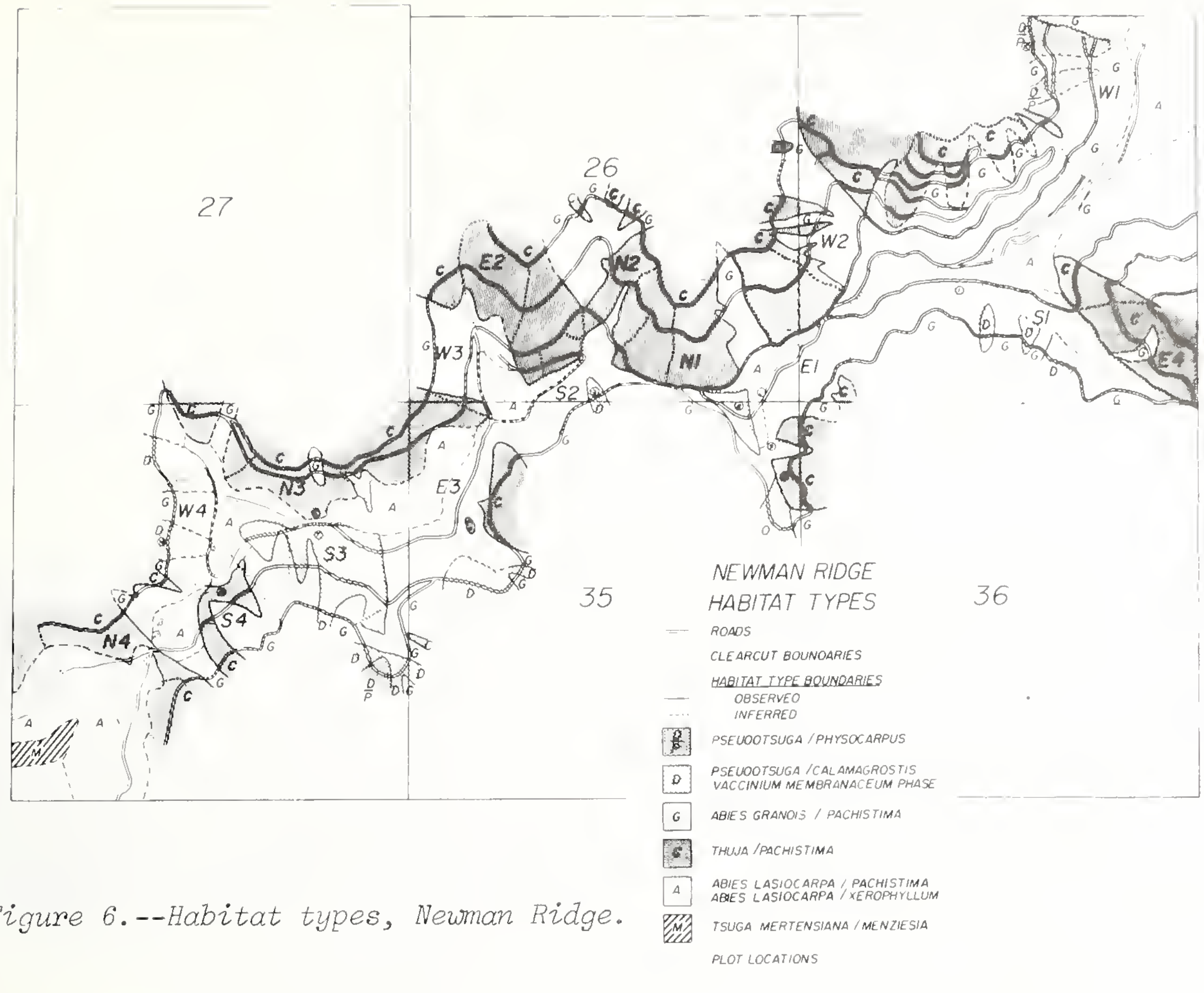

Figure 6.--Habitat types, Newman Ridge.

Table 1.--*Commercial timber volumes harvested (Scribner Decimal C)*

Block	Block size	Larch	Douglas-fir	True fir	Spruce	Lodgepole pine	Ponderosa pine	White pine	Cedar	Total volume
	(Acres)	*Thousand board feet per acre*								
					MILLER CREEK					
North	162	7.7	9.6	1.4	13.1	2.1	1/ --	--	--	33.4
East	162	7.1	4.4	2.5	11.4	2.9	--	--	--	28.3
South	159	4.7	7.6	1.4	2.6	.1	--	--	--	16.4
West	158	6.3	8.3	1.0	3.5	1.0	--	--	--	20.1
Block total or average	641	6.4	7.5	1.6	7.6	1.5	--	--	--	24.6
Percent of volume by species	--	25.7	30.6	6.5	31.1	6.2	--	--	--	100.0
					NEWMAN RIDGE					
North	129	7.0	6.6	1.3	.1	2.9	.1	1.0	0.6	19.6
East	109	4.9	6.9	3.0	2.1	2.3	--	.7	.5	20.4
South	137	3.6	6.7	.3	--	5.2	3.6	.1	--	19.5
West	151	5.1	6.0	1.0	--	2.8	3.2	.4	--	18.5
Block total or average	526	5.1	6.5	1.4	.6	3.3	1.7	1.1	.3	19.5
Percent of volume by species	--	26.4	33.6	7.3	2.8	16.9	8.8	2.8	1.4	100.0

1/ Indicates no significant volume

Miller Creek units occurred primarily within the *Abies lasiocarpa/Pachistima myrsinites* habitat type (fig. 5). Two distinct phases were recognized in addition to the generic type. A *Xerophyllum* phase occurred on most south- and west-facing slopes, and a *Menziesia* phase on north exposures. Stream bottoms supported the *Thuja plicata/Pachistima myrsinites* habitat type.

Seven habitat types were recognized on the Newman Ridge area, *Abies grandis/Pachistima* and *Thuja Plicata/Pachistima* habitats predominating (fig. 6). The former occupied concave east, northwest, and protected south slopes; the latter were found on concave north and northeast slopes. Ridges were occupied by either *Abies lasiocarpa/Pachistima* if north-facing, or *Abies lasiocarpa/Xerophyllum* if south-facing. The driest and warmest sites supported the *Pseudotsuga menziesii/Physocarpus* habitat type, while *Pseudotsuga menziesii* appeared on the driest and coolest sites. *Tsuga mertensiana/menziesii* occupied the highest elevations at Newman Ridge.

Fuel Conditions

Slash Preparation and Burning

Logging slash constitutes an extraordinary wildfire hazard soon after it is created. If the trees are felled in summer, 4 to 12 weeks are needed for slash up to 10 cm (4 inches) in diameter to be cured and reach moisture equilibrium with its environment (Olson and Fahnestock 1955; Fosberg 1970). The slash from stands cut in autumn or winter often retains its moisture until the following summer. Needles and fine twigs reach equilibrium much more quickly than the larger slash particles.

Fire managers prefer to burn slash within a year following logging, not only to reduce the fire hazard but to obtain other benefits. Slash burned soon after curing retains needles that promote the ignition and spread of broadcast fires. Slash that burns readily can be burned under a wide variety of weather conditions, is easier and cheaper to burn, and offers considerable flexibility in preparing a site for reforestation.

The study design called for burning of all exposures in spring, summer, and autumn over a 2-year period at Miller Creek and 1 year at Newman Ridge. The three-season spread had two purposes: (1) to sample soil and fuel moisture relationships throughout the snowfree season to determine their effect on burn accomplishment, and (2) to study the effects of burning on plants (both tops and root systems) at different stages of growth and maturity. Superimposing these goals on the constraints outlined in the preceding paragraph made for an ambitious schedule that was not entirely met. Experimental design also required that fuel beds be as uniform as possible in order to eliminate fuel continuity as a variable and to enhance fire spread across the unit. This was accomplished by requiring directional felling and double drum jammer skidding. Jammer roads were spaced at least 600 feet apart. All machine operation was strictly forbidden within the 2-1/2-acre sample plots. Whenever possible the uniformity of the fuel bed was enhanced by the slash crew during slashing and laydown of unmerchantable stems. Fire breaks (dozer-blade-wide) were dozed along all sides of each unit not bordered by a jammer road.

Anticipated fire behavior was the main consideration in determining if a unit was ready to burn. Fuel moisture had to be within a range where the fire could be expected to burn the entire unit. Weather had to be favorable enough to keep a fire within the designated unit.

Fuel moisture and fire weather were continuously monitored to provide information needed to evaluate a unit's readiness to burn. Weather stations were located at Miller Creek and Newman Ridge close to the clearcut units (fig. 7). Companion stations were

Figure 7.--Fire-weather station, Newman Ridge.

also located in nearby valley bottoms to identify nighttime temperature inversion, an important influence on nighttime fire behavior. Fire weather stations were operated in accordance with standard procedures (Fischer and Hardy 1972). A hygrothermograph modified to record windspeed as well as temperature and humidity (Fischer and others 1969) proved to be especially useful in identifying favorable burning conditions (Beaufait and Fischer 1969).

In the western United States, moisture content of indicator sticks has been the commonly used method for scheduling broadcast burns (Morris 1966). Standard 100-gram fuel moisture indicator sticks were installed early each season at weather stations on the study area and at units scheduled for treatment that year. Sets of fuel moisture sticks, placed at standard 10-inch height (without screens) were paired with others in adjacent uncut timber with the same slope and exposure. Sticks were weighed periodically throughout the season and immediately prior to burning.

Constraints on ignition procedures were: (a) a central and single convection column must be obtained and maintained to expedite firing and to enhance safety; (b) the 2-1/2-acre research plot would be burned by a heading fire to insure uniformity of treatment.

Specific firing plans considered each unit's peculiarities, the time-of-day, fire weather, and location relative to other units. Usually, a unit was first ignited along a line about 1 chain below its uphill edge, often by remote ignition. The uphill edge was ignited as the fire front approached it and then the unit sides were ignited. Finally, the lower edge was ignited to produce a heading, uphill fire over most of the area (fig. 8).

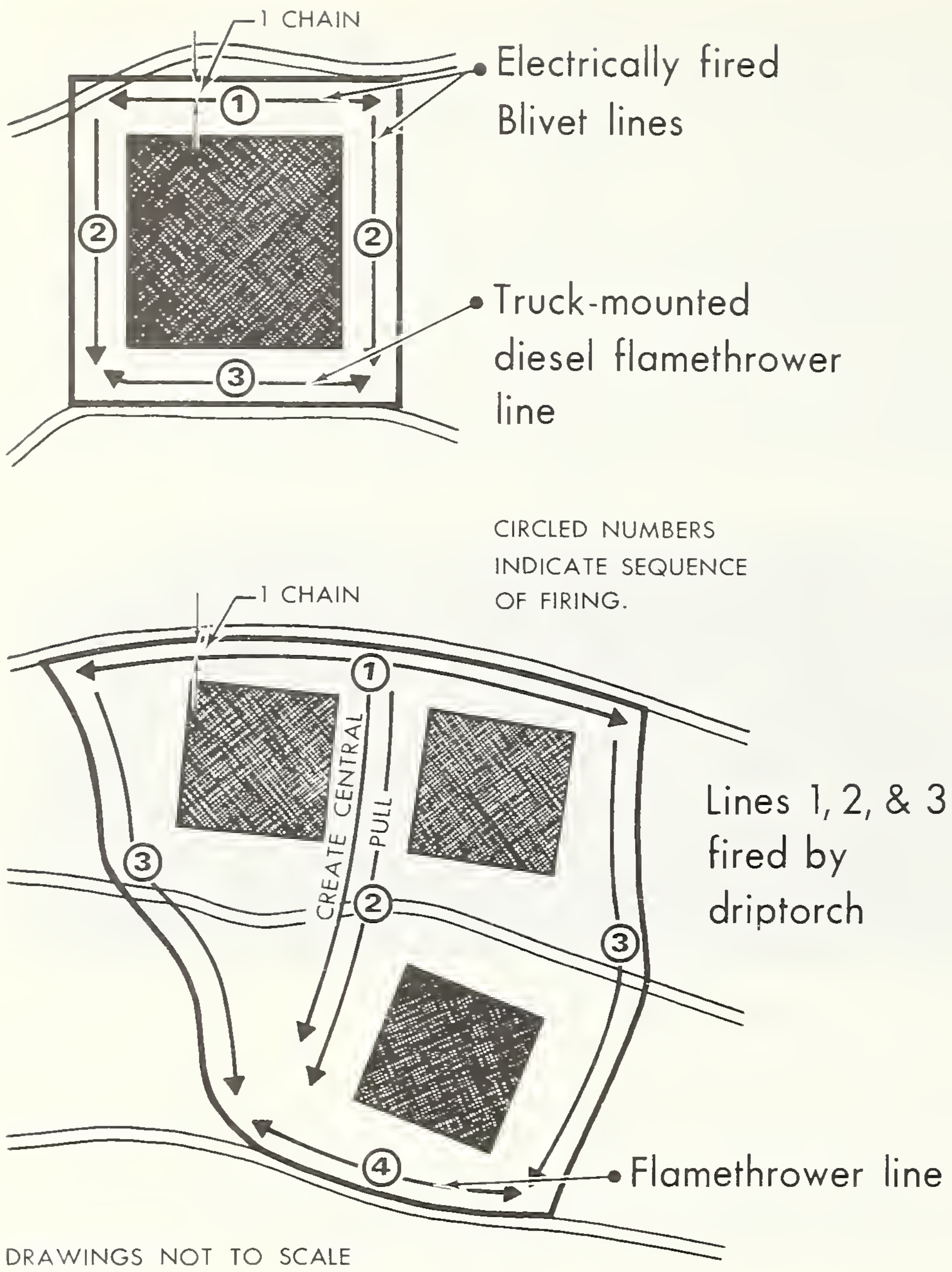

Figure 8.--Typical firing patterns for Miller Creek (above) and Newman Ridge units.

Most of the fires were ignited in late afternoon, or in the evening after winds ceased but before humidity started to rise (Beaufait and Fischer 1969). Firing was generally completed within 20 minutes on the 10-acre Miller Creek units. It sometimes took as long as 40 minutes to ignite the much larger Newman Ridge units.

The timber harvest and fire treatment schedule is detailed in appendix B. A total of 73 sample plots in 55 different units were treated. Three sample plots were burned in the spring, 54 in the summer and 16 during the autumn. The treatment record over the 3 years probably represents the realistic range of prescribed burning opportunities in the northern Rocky Mountains.

Figure 9 displays burning conditions during the 3-year study period based on the National Fire-Danger Rating System Buildup Index (USDA Forest Service 1964). Buildup index indicates overall severity of burning conditions (Fischer 1969). Figure 9 also reports the range of burning conditions sampled. Periods of "Very High" and "Extreme" fire danger were considered too dangerous for prescribed burning.

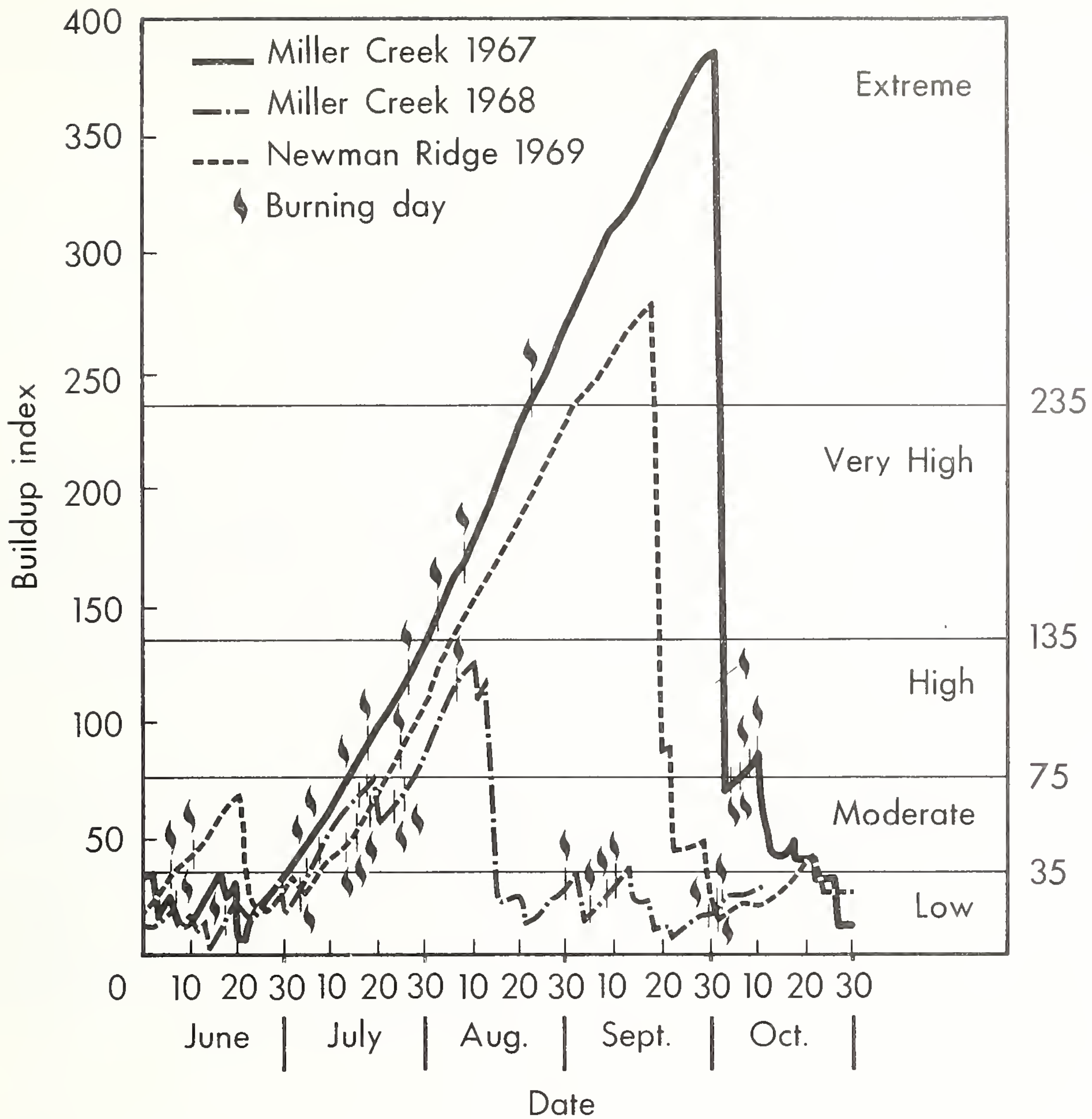

Figure 9.--Buildup Index for each of the three seasons of fire treatments at Miller Creek and Newman Ridge.

Fuel Inventory Methods

Fire intensity varies with, among other factors, the moisture content, size, and distribution of fuel particles. Slash lies in a porous bed of roughly horizontal branches, tops, and unmerchantable stems. This admixture is complicated by a range of species, utilization standards, skidding practices, and site characteristics. Slash, in turn, lies atop a mat-like organic mantle on the forest floor, the "duff" (often broken into three components--litter, duff, and decomposed humus).

After harvesting and slashing had been completed, the fuel complex on each unit had to be described by means of a method that would compare fuels before and after burning. Data were collected from approximately 7,000 systematically placed meter-long transects (66 per 2-1/2-acre plot) on both experimental blocks (fig. 4). Data included the number of woody intercepts by species and size class (< 1 cm, 1 to 10 cm, and > 10 cm), depth of slash bed, depth of organic duff, slope and exposure, and ground cover.

In addition to recording woody intercepts, slash was subsampled to determine:

a. average diameter of intercepts by species and size classes < 1 cm and 1 to 10 cm.

b. actual diameter (to nearest 10 cm) of stems > 10 cm,

c. the number, weight, volume, and surface area of leaves on twigs < 1 cm in diameter,

d. probability proportional to prediction (3P) on estimates of < 1 cm material,

e. ratios of duff dry weight to depth, and

f. bulk density or specific gravity of all fuel components.

Much of the data collected by subsampling was used in conjunction with the transect data to compute fuel loadings. Data on fuel surface area was used as an independent variable in fuel reduction regressions. Table 2 summarizes, by species, data collected by subsampling fuels.

Table 2.--*Fuel physical data (mean diameter, specific gravity, conversion ratios)*

Fuel parameter	Species								
	Ponderosa pine	Douglas-fir	Larch	Lodgepole pine	Spruce	True fir	Cedar	Yew	Hardwoods
0 to 1 cm mean diameter (cm)	0.69	0.20	0.26	0.42	0.20	0.24	0.32	0.12	0.18
1 to 10 cm mean diameter (cm)	2.92	3.05	3.03	3.87	2.19	2.30	2.26	2.50	2.50
Specific gravity needles	.51	.56	.62	.56	.56	.52	.41	.52	.56
Specific gravity 0 to 1 cm	.41	.55	.46	.49	.34	.41	.48	.50	.45
Specific gravity 1 to 10 cm	.51	.43	.55	.41	.34	.40	.33	.55	.45
Specific gravity 10 to 90 cm	.51	.43	.55	.41	.34	.40	.33	.55	.45
Needle weight to branch weight ratio	2.52	1.18	.27	1.03	1.36	1.42	2.08	.76	1.09
Needle surface to volume ratio	57.6	69.1	184.0	64.7	54.2	69.1	80.5	69.1	85.0

Ratios of dry weight to depth were used to develop regression equations for predicting duff weight from pre- and postburn measurements of duff depth. The equations developed are as follows:

	MILLER CREEK	*NEWMAN RIDGE*
North units	$\hat{Y} = -10.41 + 12.98X$	$\hat{Y} = 12.96 + 8.17X$
East units	$\hat{Y} = 15.33 + 13.72X$	$\hat{Y} = -5.04 + 11.12X$
South units	$\hat{Y} = 13.49 + 9.16X$	$\hat{Y} = 17.26 + 7.24X$
West units	$\hat{Y} = -5.42 + 13.69X$	$\hat{Y} = 6.39 + 11.17X$

Where: $\hat{Y}$ = predicted duff weight (gms in a 5-inch cylinder)

X = measured duff depth (cms)

These equations give the predicted weight in a 5-inch-diameter soil sample cylinder. We multiplied $\hat{Y}$ value by 0.352217 to obtain duff loadings in tons/acre (by 0.078976 to get kg/m^2).

Fuel inventory techniques used in this study have been reported by Beaufait, Marsden, and Norum (1974). Since this pioneering attempt, fuel inventory techniques have been refined. Recent work by Brown (1974) describes current methodology.

Fuel Loads

Preburn fuel loads, exclusive of duff, varied from 60 to 165 tons/acre (14 to 37 kg/m^2) among individual units. When grouped by exposure, however, the average loadings showed remarkable uniformity (table 3). Miller Creek units supported slightly higher slash loadings than those at Newman Ridge: 114 tons/acre compared to 104 tons/acre (25 kg/m^2 vs 23 kg/m^2). Size distribution within units was also quite similar. Approximately 88 percent of the slash fuel weight, exclusive of duff, was accounted for by material greater than 10 cm in diameter; 10 percent by material 1 to 10 cm in diameter; and 1 percent each for twigs (0 to 1 cm in diameter) and needles.

Table 3.--*Summary of preburn fuel loads by exposure and size class (tons per acre)*

Exposure	Duff		Down and Dead Stem and Branchwood Components								Average load
			Needles		0 to 1 cm		1 to 10 cm		>10 cm		
	Mean weight	Std. dev.	Mean weight	Std. dev.	Mean weight	Std. dev.	Mean weight	Std. dev.	Mean weight	Std. dev.	
					MILLER CREEK						
North	21.75	8.20	1.66	0.42	1.33	0.34	8.92	3.35	107.84	21.18	141.50
East	41.13	7.08	1.64	.32	1.38	.24	11.61	3.05	94.91	18.62	150.67
South	23.81	3.34	1.36	.33	1.17	.21	10.24	2.66	107.55	28.81	144.13
West	18.65	7.70	1.48	.44	1.26	.37	8.57	3.14	94.77	23.29	124.73
Block average	26.34	10.09	1.54	0.14	1.29	0.09	9.84	1.38	101.27	7.42	140.26
					NEWMAN RIDGE						
North	27.03	2.58	1.39	0.55	1.06	0.24	8.56	1.31	94.76	26.21	132.85
East	19.07	3.54	1.00	.47	.83	.27	9.10	2.55	86.10	15.59	116.10
South	23.09	1.29	1.78	.66	1.36	.29	12.99	4.82	83.17	15.00	122.39
West	22.20	4.44	1.39	.63	1.20	.34	12.22	4.07	97.81	14.93	134.32
Block average	22.86	3.30	1.39	0.32	1.11	0.22	10.72	2.21	90.46	6.94	126.54

Table 4.--*Average duff depth by exposure*

Exposure	Miller Creek: Mean depth cm	Miller Creek: Standard deviation	Newman Ridge: Mean depth cm	Newman Ridge: Standard deviation
North	6.43	1.48	6.24	0.90
East	6.27	1.47	5.77	.90
South	4.43	1.04	4.35	.42
West	4.66	1.60	4.50	1.13
Block average	5.45	0.91	5.22	0.93

Brown (1970) investigated the vertical distribution of fuel particles in the slash at Miller Creek. He found that about 68 percent of both the fuel volume and fuel surface area was concentrated in the lower portions of the slash (i.e. below the average mid-depth of the slash).

In the Miller Creek slash, Brown (1970) also noted a high frequency (40 percent of transects) of needle mats caught on branches.

Duff weight on individual units varied between 4 and 50 tons/acre (0.90 and 11 kg/m^2) at Miller Creek and between 15 and 29 tons/acre (3 and 7 kg/m^2) at Newman Ridge. Average duff weight for Miller Creek units was about 26 tons/acre (5.9 kg/m^2) compared to about 23 tons/acre (5.1 kg/m^2) for Newman Ridge units. Duff depth averaged 5.45 cm at Miller Creek and 5.22 cm at Newman Ridge. North and east exposures supported deeper duff on the average than did south and west exposures (table 4).

Preharvest stand examination procedures commonly used in the Northern Region (USDA Forest Service 1965) were modified to include collection of additional data on standing and down sound and dead trees, duff depth, and ground cover vegetation. The expanded stand examination data was then correlated with the fuel inventory to test the feasibility of predicting fuel loads that would result from clearcutting in larch/fir. The attempts failed because sampling was insufficient to account for natural variation and because crown weight data were inadequate. Current work by Brown[3] will result in a much improved capability for such predictions in the near future.

Fuel Moisture

Moisture contents of various components of the fuel complex were utilized as independent variables in burn accomplishment regression equations. Samples of needles, twigs, and branches were collected from several heights within the slash over each of three sample points within each unit. Samples of litter and duff were also collected at each sample point. Sampling was always done just before burning.

[3]Brown, James K. Prediction of tree crown weights and size distribution of crown components. Study Plan 2104-17 on file at the Northern Forest Fire Laboratory, Missoula, Montana.

Methods for determining moisture content varied with the size and wetness of the samples. Small, relatively dry material was ground in an intermediate Wiley mill and evaluated titrimetrically using Karl Fischer reagent. Large, moist, samples were weighed before and after ovendrying at 105° C.

A range of preburn fuel moisture conditions were measured on each of the four exposures, as indicated by the average values shown in appendix C. Replication of similar moisture conditions both within each exposure as well as between exposures was also achieved. Similar fuel moisture conditions occurred throughout the 6-month period in which burning was accomplished (appendix D).

Range and frequency of moisture content of various fuel components are illustrated in figure 10. The upper duff exhibited the widest range of fuel moisture of any of the components sampled. As will be seen later, upper duff moisture content proved to be an important predictor of burn accomplishment. Although litter exhibited a fairly wide range of moisture retention, moisture content was 5 percent or less on half the units burned. The larger twig and branch components displayed a more uniform frequency of moisture content than the duff and litter but over a narrower range of moisture conditions.

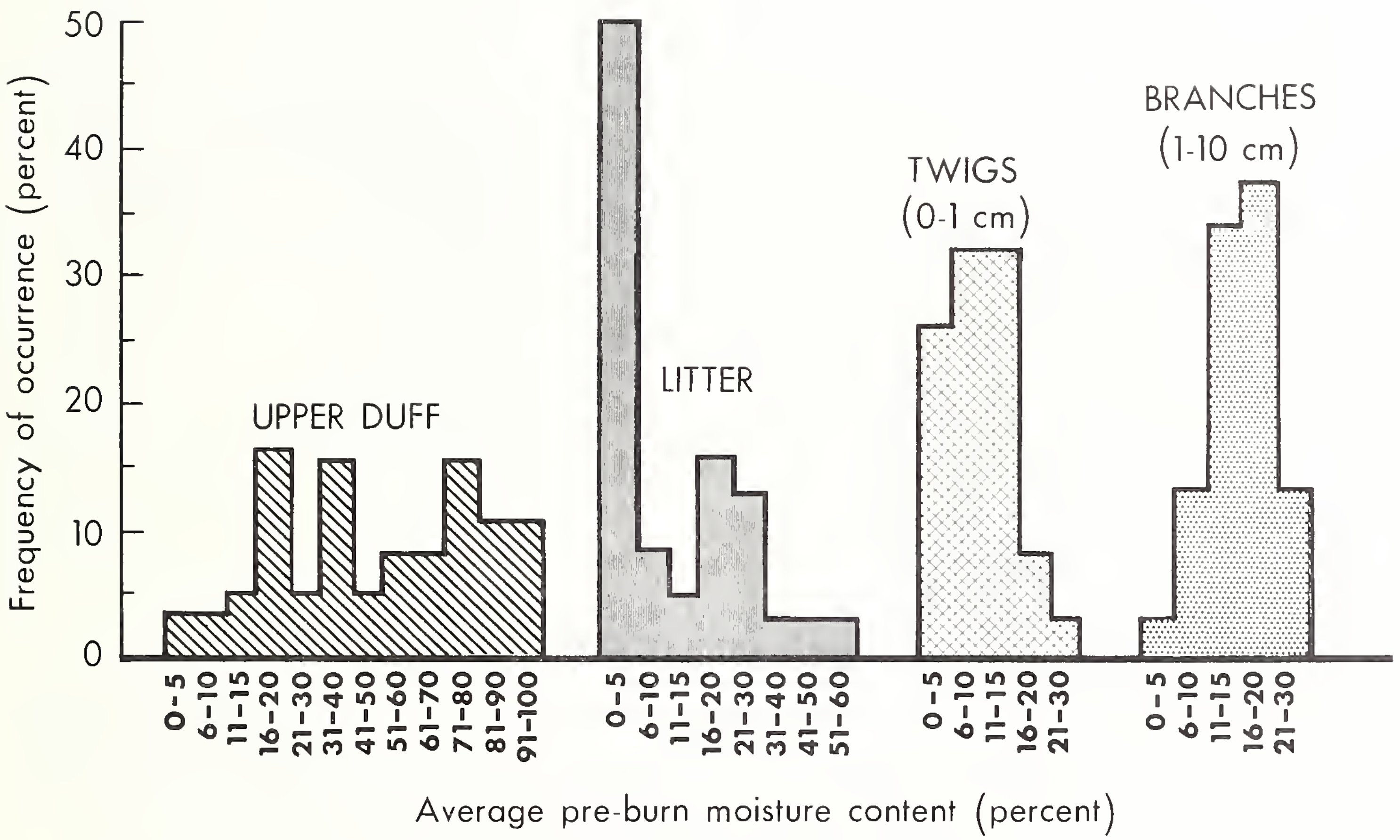

Figure 10.--Range and frequency of preburn moisture contents for selected fuel bed components.

Attempts to Predict Fuel Moisture

In actual practice, land managers seldom measure fuel moisture directly but instead rely on predictions from indicator sticks or fire-danger rating systems. Consequently, current fire-danger moisture indices were calculated and examined along with other independent variables in burn accomplishment regression equations. Moisture indices tests were Buildup Index (BUI), Fine Fuel Moisture (FFM) and Adjusted Fine Fuel Moisture (AFM). All of these indices were components of the Spread Phase, National Fire-Danger Rating System (USDA Forest Service 1964). All are calculated from various combinations of temperature, relative humidity, and precipitation observed at on-site weather stations. Because their use was not included in the then current fire-danger rating system, indicator stick data was not included in burn analysis.

The predictive capability of indicator sticks and fire-danger rating indices was also evaluated by comparing their values with laboratory determined moisture content. Table 5 shows the results of this evaluation. Buildup Index showed a fair to good correlation with measured moisture content of the duff under standing timber. Fine Fuel Moisture and Adjusted Fuel Moisture values did not relate very well to actual moisture content of needles on or in the duff. The moisture content of 1/2-inch fuel moisture sticks showed better correlation with needle moisture than did any of the fire-danger indices.

Table 5.--*Simple linear correlation coefficients between actual litter and duff moisture content and predictors of fuel moisture*

Predictor	Moisture content		
	Litter	Upper half of duff	Lower half of duff
	Coefficients of determination (R^2)		
NFDRS Fine Fuel Moisture	0.31	0.30	0.27
NFDRS Adjusted Fuel Moisture	.46	.51	.49
NFDRS Buildup Index	.37	.63	.74
1/2-inch ponderosa pine fuel moisture sticks	.55	.36	--

Burn Evaluation

Burn evaluation was guided by the study objectives, which in turn were a reflection of management needs. Consequently, it was imperative to quantify burn accomplishment in terms of duff reduction and fuel loss, and to characterize the experimental fires in a way that allowed a ranking of relative fire intensity. Fire effects could then be evaluated in terms of the character (cool vs hot) of the fires. To this end, water can analogs were used to obtain a value for heat pulse to the site. Several other methods of evaluating fire intensity were also explored but proved less productive.

Regression equations presented here summarize recent experience with slash burning and its direct effects in the western larch/interior Douglas-fir forest type in Montana. The equations describe the relationships among fire accomplishments, fuel, and weather. The equations are not predictive statistically but are applicable to large areas in the northern Rocky Mountains where vegetative and topographic characteristics are similar to the study area.

Duff Reduction

Although the organic mantle on the forest floor may appear uniform and matlike on its surface, it is uneven along its contact with mineral soil. Buried, partly decomposed stems and stumps are often interspersed with rocks protruding into the duff. The irregularity of this inorganic-organic interface often complicates attempts to describe duff depth before burning and duff loss from a fire.

Changes in the duff mantle due to burning were measured as follows: (1) direct measurement of depth during preburn and postburn fuel inventories, and (2) installation of spikes in the soil before burning, with subsequent recording of changes in the duff level. In the former method, the duff depth was measured at three points along each of the 66 1-meter-long fuel inventory transects on all plots. The average depth per transect was recorded to the nearest centimeter in the fuel inventory. This process was repeated after burning, and the average loss per plot computed.

In the latter method, large spikes (8-inches long) were driven into the soil until the heads were flush with the surface of undisturbed preburn duff (fig. 11). Spikes were located 1/2-meter on either side of each inventory point. After each fire, ashes were blown away from the spikes and the exposed spike length was recorded. In this way, preburn and postburn duff depths were observed on identical points. These data also served as dependent variables in the duff reduction analyses, and also as dependent variables in the analysis of fire effects.

Heating may cause temporary swelling of duff and consequently overestimation of depth; therefore, postburn depth was measured after precipitation washed the ashes away and resettled the duff.

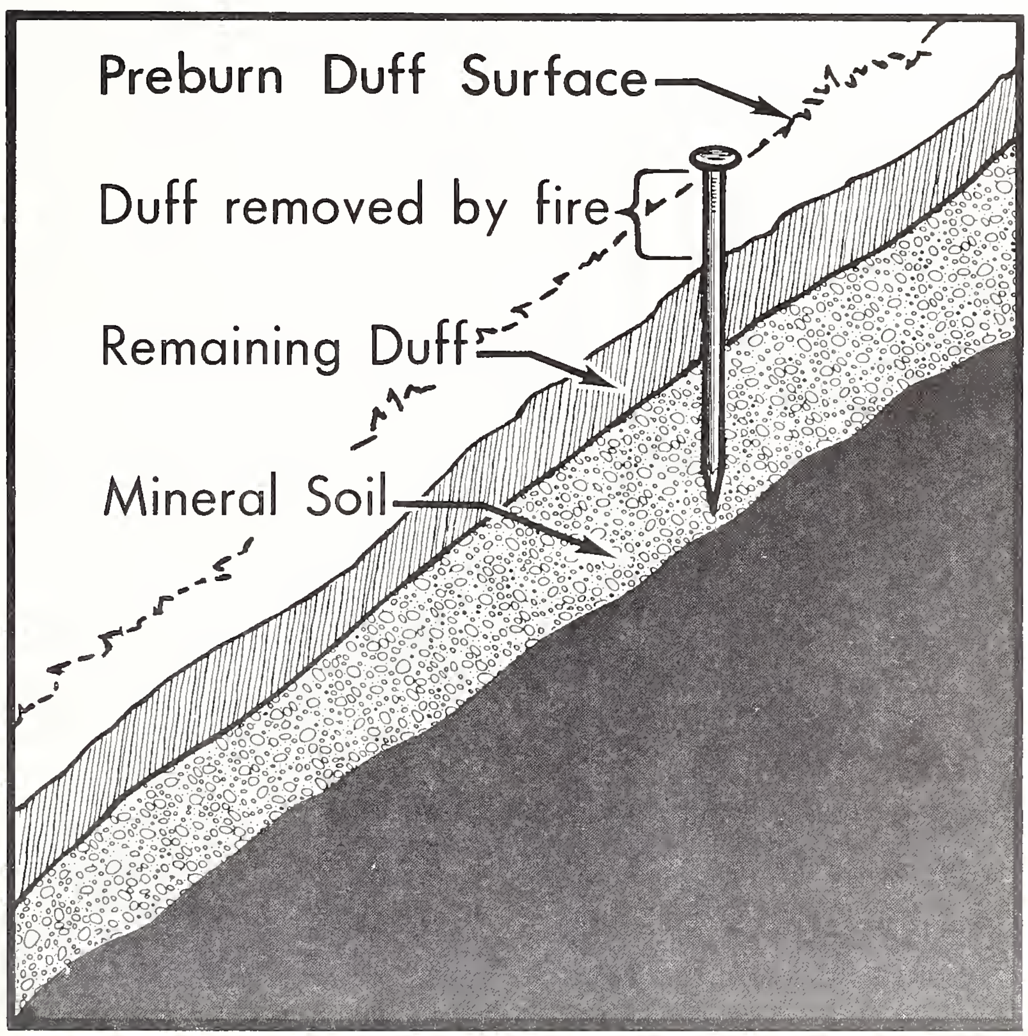

Figure 11.--Spike installation to determine duff reduction.

The original study plan called for expressions of fire's direct effect both through actual duff removed and the percentage of mineral soil exposed. Of these two variables, duff loss measurements obtained from the spikes proved to be most reliable. Although mineral soil exposure was recorded at the same time as duff depth (preburn and postburn fuel inventories), internal plot variability obscured slight changes that may have occurred in the percentage of exposed mineral soil in postburn transects.

The equation describing actual reduction in duff depth by broadcast burning quantifies the obvious--the drier the fuel, the deeper the burn. Two different expressions of duff moisture were used as independent variables: (1) Buildup Index (BUI) and (2) measurement of moisture content.

The equation of best fit for duff depth reduction was:

$$Y(2) = f\left(X(2),\ X(7),\ X(12)\right)$$

$$Y(2) = \left(1.0719 - 0.0161X(2) + 0.03215X(7) + 0.0740X(12)\right)$$

Where:

Variable	*Description*	*Range*	*"t"*	*Level of Significance (percent)*
Y(2)	Duff depth reduction	0 to 6.1 cm		
X(2)	Upper duff moisture content	7.5 to 99+ percent	4.5	99.9
X(7)	Buildup Index	15 to 237	5.1	99.9
X(12)	$\sqrt{\text{Buildup Index}}$		6.8	99.9

Standard error of regression = 0.801 cm

"F" = 46.7 (with 4 and 60 degrees of freedom)

$F_{(4,\ 60,\ \alpha\ =\ .01)} = 3.65$

Additional variables tested:

X(1) = needle moisture content

X(3) = slash depth

X(4) = 1 to 10 cm fuel weight

X(5) = adjusted fine fuel moisture

X(6) = lower duff moisture

X(8) = 1/weight of 1 to 10 cm

X(9) = 1/fine fuel moisture

X(14) = 1/X(5)

Table 6.--*Duff depth reduction*[1/]

Upper duff moisture content (Percent)	Buildup index 10	35	60	85	110	135	160	185	210	235	260
	Cm										
5	2	3	3	4	5	6	7	8	9	10	11
10	1	2	3	4	5	6	7	8	9	10	10
15	1	2	3	4	5	6	7	8	9	10	10
20	1	2	3	4	5	6	7	8	9	9	10
25	1	2	3	4	5	6	7	8	8	9	10
30	1	2	3	4	5	6	7	8	8	9	10
35	1	2	3	4	5	6	7	7	8	9	10
40	1	2	3	4	5	6	7	7	8	9	10
45	1	2	3	4	5	6	6	7	8	9	10
50	1	2	3	4	5	5	6	7	8	9	10
55	1	2	3	4	4	5	6	7	8	9	10
60	1	2	3	4	4	5	6	7	8	9	10
65	1	2	3	3	4	5	6	7	8	9	10
70	1	2	2	3	4	5	6	7	8	9	9
75	0	1	2	3	4	5	6	7	8	9	9
80	0	1	2	3	4	5	6	7	8	8	9
85	0	1	2	3	4	5	6	7	8	8	9
90	0	1	2	3	4	5	6	7	7	8	9
95	0	1	2	3	4	5	6	6	7	8	9
100	0	1	2	3	4	5	6	6	7	8	9

[1/] Approximate range of collected data is indicated by internal line.

Table 6 contains solutions of the equation of best fit for various combinations of duff moisture and Buildup Index. This table can be used to estimate duff reduction for sites and treatments similar to those studied. The table also reflects that the accumulated dryness variable, represented by the Buildup Index, becomes increasingly important as duff gets deeper.

Fuel Loss

Fuel loss was evaluated by reinventorying fuels after each fire. Meter-long transects at random angles from the contour were installed at the same points used for preburn fuel inventory. Table 7 summarizes preburn and postburn fuel inventories. Preburn fuel weights reflect loadings prior to burning. Because some plots were not burned or were lost in wildfires, in some cases these values differ from those listed in table 3.

Pre- and postburn fuel sampling intensity was based on the erroneous assumption that the fuels larger than 10 cm are generally not consumed by prescribed fires; consequently, fuels larger than 10 cm were sampled less intensely than those smaller than 10 cm. As a result of this sampling error, inventories of material larger than 10 cm are only suggestive of actual volumes contained in that size class. Therefore, in this report fuel loss mainly includes: (1) leaves suspended on slash, (2) twigs < 1 cm in diameter, and (3) branches 1 to 10 cm in diameter.

Table 7.--*Fuel quantities before and after broadcast burning*

Fuel size	Miller Creek[1]			Newman Ridge[2]		
	Preburn quantity	Quantity burned	Percentage burned	Preburn quantity	Quantity burned	Percentage burned
	- - - *tons/acre* - - -			- - - *tons/acre* - - -		
Needles	1.54	1.54	100.00	1.56	1.56	100.00
0 to 1 cm	1.29	1.12	87.00	1.14	1.05	92.00
1 to 10 cm	9.84	6.78	69.00	12.10	10.62	88.00
Subtotal	12.67	9.44	75.00	14.80	13.23	89.00
> 10 cm	101.27	59.60	60.00	93.49	51.66	55.00
Total	113.94	69.04	61.00	108.29	64.89	60.00

[1]Average of 41 plots.
[2]Average of 24 plots.

Analysis of the fuel loss data indicates that regardless of fuel loading, burning condition, or aspect, the percentage of fuel consumed is in inverse relation to its size (table 7). An acceptable fuel loss equation was not derived because of treatment bias between fuel loadings and fuel moisture content. The equation is reported here only to illustrate the probable sources of bias. Bias was caused by a natural tendency to burn units having large amounts of fuel under relatively safe fire-weather conditions. Thus, units with light loads were left to be burned during the more severe conditions. Reinforcing this tendency is the fact that heavier fuels generally occur on cool, moist, north and east exposures. By the same token, light fuels generally occur on more severe south and west exposures where moisture contents are generally lower.

The equation of best fit for fuel weight loss is:

$$Y(4) = f\ X(4),\ X(7),\ X(11)$$

$$Y(4) = -258.37 + 0.8651X(4) - 2.629X(7) + 4{,}540.8X(11)$$

where:

Variable	*Description*	*Range*	*"t"*	*Level of significance (percent)*
Y(4)	Fuel weight loss, 0 to 10 cm and needles	0.289 to 4.30 kg/m^2 (1.2 to 19.2 tons/acre)		
X(4)	Fuel weight, 1 to 10 cm	1.033 to 4.770 kg/m^2 (4.6 to 21.3 tons/acre)	25.00	99.9
X(7)	NFDRS BUI	1.5 to 237	18.20	99.9
X(11)	1/upper duff moisture content	0.0101 to 0.1333	4.49	99.9

Standard error of regression = 2.113

"F" = 36.23 (with 3 and 61 degrees of freedom)

$F_{(3,\ 61,\ \alpha\ =\ 0.01)} < F_{(3,\ 60,\ \alpha\ =\ 0.01)} = 4.13$

Additional variables tested:

X(1) = needle moisture content

X(6) = lower duff moisture content

X(10) = 1/needle moisture content

X(23) = surface area of needles

X(28) = 0 to 1 cm weight (g/m^2)

X(29) = 10+ cm fuel weight (g/m^2)

X(30) = fine fuel moisture

X(31) = 1/Buildup Index

The magnitude of bias became apparent when the equation of best fit provided data that were obviously incorrect. The fact that the coefficient for Buildup Index, X(7), is negative and highly significant implies that the higher the Buildup Index (or the drier the fuels) the smaller will be the amount consumed by fire. (Actually the drier the fuels the more consumed.) Several unsuccessful attempts were made to normalize this bias; consequently, we were not able to predict the amount of fuel loss based on preburn fuel or duff weight, moisture content, and weather.

In lieu of a mathematical relationship describing fuel losses, a set of case histories is offered (table 8). Fuel loadings and fuel losses are listed along with the BUI and the moisture content of the 0 to 1 cm fuels at the time of the fires. These data, although not suitable for statistical analyses, are accurate and represent a large number of carefully documented fires. This table may prove useful to those who contemplate burning similar fuels under similar moisture conditions. Each fire should be considered separately on its own characteristics. Caution should be exercised in comparing individual fires.

Fire Characterization

Fires were characterized by measuring the heat pulse to the site, which allowed the ranking of *relative* intensity. Several techniques for estimating fire intensity--the amount of energy emitted from an area in a unit of time--were also tried.

Heat Pulse to the Site

Heat pulse to the site was measured with Beaufait's (1966a) water-can analog, a water-filled, 1-gallon paint can sprayed black. The water that evaporates through a hole in the lid is proportional to the energy released by the fire in which it is placed (George 1969).

Standardized placement, recovery, and measurement of water-can analogs permits objective comparison among fires of varying severity, and a common vocabulary among land managers and fire researchers.

Table 8.--*Fuel weight loss due to fire for each unit*

MILLER CREEK

Unit	Size class, Preburn fuels: Needles	0-1	1-10	Subtotal	>10	Total	Fuel loss 0-10 + needles	BUI	Fuel moisture (0-1 cm)
	Kg/m²								(percent)
N4	0.311	0.257	2.163	2.731	20.460	23.191	2.090	35	14
N5	.302	.246	1.875	2.423	22.928	25.351	1.981	70	16
N6	.241	.187	2.743	3.171	26.106	29.277	2.493	29	16
N7	.401	.336	2.339	3.076	28.513	31.589	2.576	15	12
N8	.389	.302	3.540	4.231	30.737	34.968	3.537	29	16
N9	.294	.223	1.216	1.733	23.402	25.135	1.488	70	10
N11	.596	.482	2.825	3.903	29.543	33.446	2.962	145	8
N12	.442	.336	2.258	3.036	32.412	35.448	2.197	145	8
N13	.372	.312	1.082	1.766	17.664	19.430	1.418	49	14
N14	.376	.294	2.368	3.038	22.328	25.366	2.384	24	27
N15	.362	.305	1.533	2.200	11.876	14.076	1.551	24	26
E1	.318	.248	1.963	2.529	29.352	31.881	1.621	72	33
E3	.337	.300	1.842	2.479	19.703	22.182	2.278	114	21
E4	.475	.378	2.333	3.186	17.339	20.525	2.705	72	17
E5	.355	.288	2.887	3.530	22.558	26.088	3.040	39	12
E6	.395	.326	1.727	2.448	23.093	25.541	1.080	87	15
E7	.474	.410	3.641	4.525	24.082	28.607	3.400	88	17
E10	.354	.293	1.940	2.587	22.100	24.687	1.979	26	15
E13	.245	.249	2.427	2.921	16.777	19.698	1.549	237	7
E14	.362	.300	2.061	2.723	16.526	19.249	1.877	26	15
S1	.325	.292	2.517	3.134	17.480	20.614	2.558	23	11
S4	.300	.233	3.207	3.740	19.707	23.447	3.314	30	9
S5	.324	.302	1.372	1.998	26.199	28.197	1.350	18	20
S7	.231	.203	1.791	2.225	33.655	35.880	1.507	237	7
S8	.192	.212	2.680	3.084	28.691	31.775	2.288	164	19
S9	.346	.270	2.295	2.911	16.183	19.094	2.470	62	16
S10	.411	.322	2.215	2.948	26.881	29.829	2.518	30	9
W1	.591	.509	3.761	4.861	27.561	32.422	4.065	111	13
W2	.355	.296	1.856	2.507	25.216	27.723	1.837	237	7
W3	.254	.208	1.777	2.239	19.931	22.170	1.773	18	20
W4	.295	.296	1.587	2.178	17.876	20.054	1.649	18	18
W5	.222	.218	2.525	2.965	19.649	22.614	1.868	237	7
W7	.295	.230	1.699	2.224	23.571	25.795	1.122	237	7
W8	.480	.400	1.033	1.913	28.625	30.538	1.692	64	15
W9	.357	.271	1.556	2.184	16.182	18.366	1.832	64	17
W10	.244	.192	2.479	2.915	16.984	19.899	2.708	68	8
W11	.377	.309	2.066	2.752	27.117	29.869	2.451	23	10
W12	.305	.262	2.107	2.674	22.925	25.599	2.013	32	17
W13	.294	.290	1.195	1.779	17.174	18.953	1.231	32	17
W14	.291	.256	2.147	2.694	22.261	24.955	2.133	32	17
W15	.278	.229	1.120	1.627	32.415	34.042	1.189	22	17

NEWMAN RIDGE

Unit	Size class, Preburn fuels: Needles	0-1	1-10	Subtotal	>10	Total	Fuel loss 0-10 + needles	BUI	Fuel moisture (0-1 cm)
	Kg/m²								(percent)
N1-1	0.196	0.171	2.370	2.737	22.729	25.466	2.268	42	10
N1-2	.509	.314	1.747	2.570	17.417	19.987	2.364	42	10
N1-3	.496	.300	1.641	2.437	34.204	36.641	2.230	42	10
N2-1	.237	.157	1.866	2.260	22.860	25.120	1.954	88	13
N2-2	.359	.256	2.193	2.808	29.195	32.003	2.278	88	13
N2-3	.476	.270	1.742	2.488	18.648	21.136	2.243	88	13
N3-1	.203	.226	2.445	2.874	17.623	20.497	--	--	--
N3-2	.149	.174	1.730	2.053	16.470	18.523	--	--	--
N3-3	.169	.179	1.960	2.308	12.349	14.657	--	--	--
N4-1	.335	.298	2.160	2.793	25.476	28.269	--	--	--
N4-2	.299	.265	1.685	2.249	21.624	23.873	--	--	--
N4-3	.307	.234	1.492	2.033	16.356	18.389	--	--	--
E1-1	.126	.140	3.142	3.408	20.724	24.132	3.178	38	12
E1-2	.118	.109	2.735	2.962	15.597	18.599	2.781	38	12
E1-3	.221	.191	2.432	2.844	22.386	25.230	2.680	38	12
E2-1	.109	.123	1.579	1.811	25.356	27.167	--	--	--
E2-2	.258	.198	1.646	2.102	15.267	17.369	--	--	--
E2-3	.468	.304	1.740	2.512	19.417	21.929	--	--	--
E3-1	.236	.199	1.479	1.914	13.938	15.852	1.502	90	13
E3-2	.285	.256	2.116	2.657	20.456	23.113	2.199	90	13
E3-3	.189	.146	1.487	1.822	20.613	22.435	1.407	90	13
S1-1	.649	.347	4.770	5.766	16.307	22.073	5.506	29	5
S1-2	.705	.412	4.467	5.584	16.802	22.382	5.447	29	5
S1-3	.525	.409	4.658	5.592	14.874	20.466	5.358	29	5
S2-1	.264	.247	2.606	3.117	25.154	28.271	2.708	56	8
S2-2	.247	2.640	2.668	3.179	15.893	19.072	2.796	56	8
S2-3	.250	.252	2.477	2.979	23.045	26.024	2.340	56	8
S3-1	.373	.370	2.889	3.632	22.653	26.285	--	--	--
S3-2	.449	.312	2.571	3.322	14.937	18.269	--	--	--
S3-3	.351	.287	2.850	3.488	17.791	21.279	--	--	--
S4-1	.401	.307	1.606	2.314	16.156	18.470	--	--	--
S4-2	.273	.216	1.719	2.208	18.950	21.158	--	--	--
S4-3	.308	.234	1.681	2.223	21.210	23.433	--	--	--
W1-1	.462	.406	4.724	5.592	20.821	26.413	4.985	43	11
W1-2	.700	.414	3.856	4.970	14.048	19.018	4.496	43	11
W1-3	.406	.276	3.936	4.618	26.260	30.878	3.927	43	11
W2-1	.216	.190	1.950	2.356	22.284	24.640	2.129	63	9
W2-2	.263	.242	2.073	2.578	26.970	29.548	2.319	63	9
W2-3	.265	.190	1.991	2.446	21.841	24.287	2.300	63	9
W3-1	.168	.167	1.926	2.261	19.408	21.669	--	--	--
W3-2	.248	.244	2.000	2.492	25.900	28.392	--	--	--
W3-3	.187	.209	3.136	3.532	21.752	25.284	--	--	--
W4-1	.275	.249	2.573	3.147	19.825	22.972	--	--	--
W4-2	.281	.320	2.523	3.124	21.713	24.837	--	--	--
W4-3	.277	.278	2.191	2.746	22.337	25.083	--	--	--

Thirty-six water cans were installed on a 1-chain grid over each 2-1/2-acre sample plot. Cans were placed through the duff directly on the mineral soil surface (fig. 12) and holes were punched in the lids before burning. Immediately after the fires cooled the cans were weighed to determine how much of the original 3 kg of water had been evaporated (fig. 13).

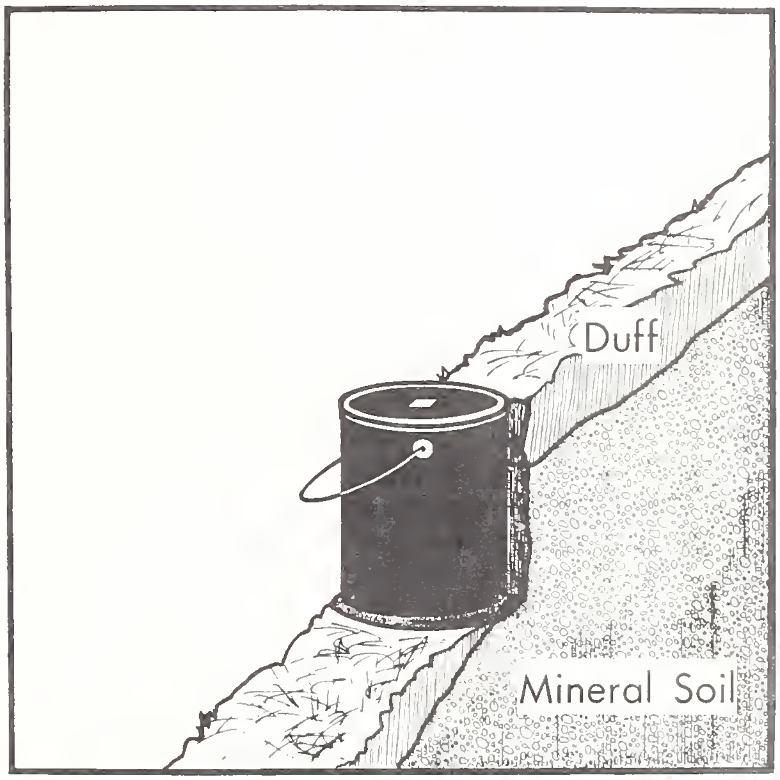

Figure 12.--Placement of water-can analog to measure heat pulse.

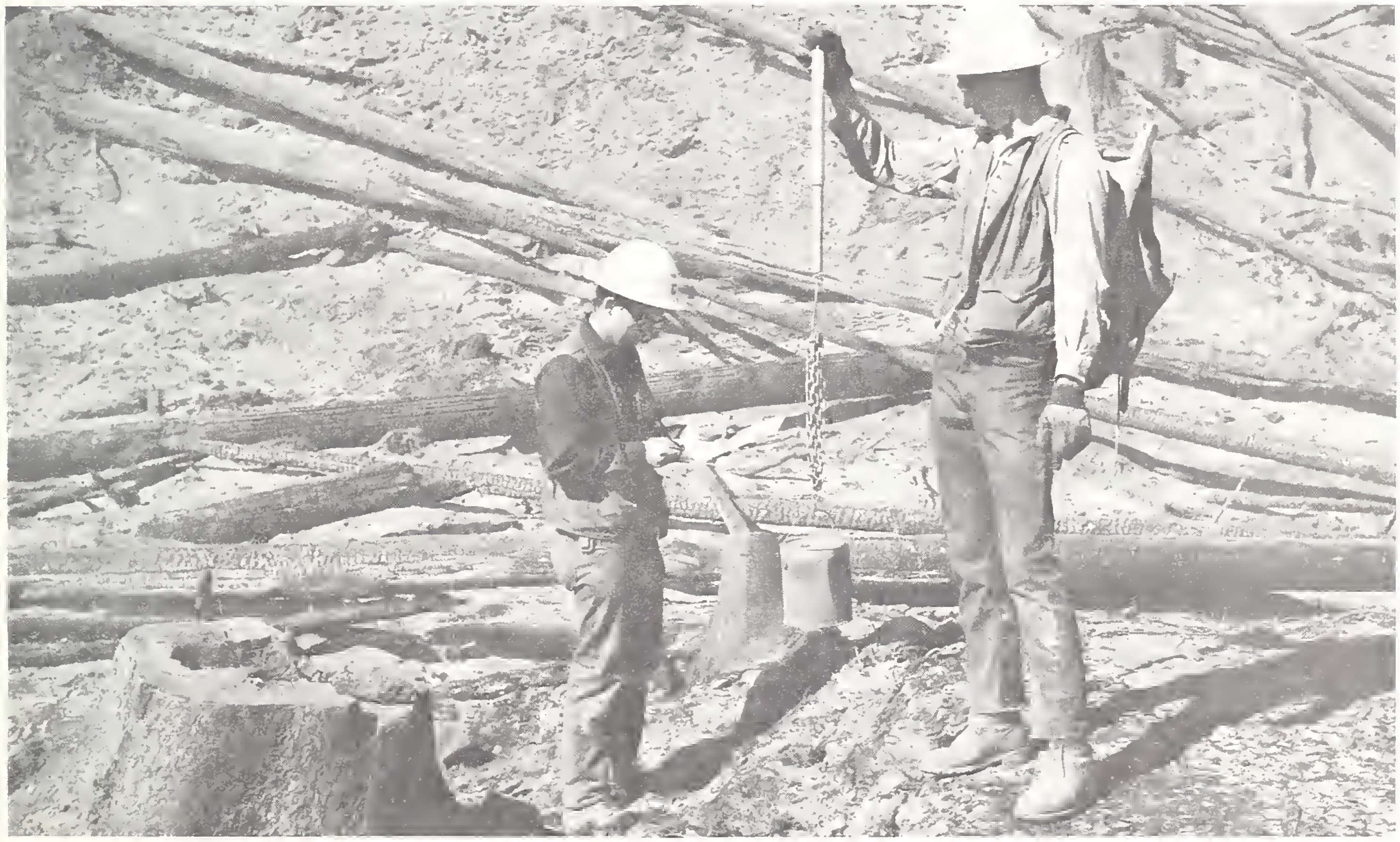

Figure 13.--Weighing water cans immediately after each fire helped characterize the heat pulse to the site.

Two expressions of fuel moisture are included as independent variables in the equation of best fit describing water can weight loss:

$$Y(1) = f\left(X(2),\ X(12)\right)$$

$$Y(1) = 336.45 - 5.53X(2) + 84.31X(12)$$

where:

Variables	*Description*	*Range*	*"t"*	*Level of significance (percent)*
Y(1)	Weight loss from water-can analogs	52.5 to 1,926.1 grams		
X(2)	Moisture content of upper duff	7.5 to 99+ percent	6.26	99.9
X(12)	Buildup Index	BUI 15 to 237	9.06	99.9

Standard error of regression = 211.38 grams

$$F_{(2,\ 62\ \alpha\ =\ 0.01)} < F_{(2,\ 60\ \alpha\ =\ 0.01)} = 4.98$$

Best equations were:

	R^2
$Y(1) = f\left(X(1),\ X(2),\ X(3),\ X(6),\ X(12)\right)$	0.77
$Y(1) = f\left(X(1),\ X(2),\ X(12)\right)$	.76
$Y(1) = f\left(X(2),\ X(12)\right)$	.74

Additional variables tested:

X(1) = needle moisture content

X(3) = slash depth

X(4) = 1 to 10 cm fuel weight

X(5) = adjusted fine fuel moisture

X(6) = lower duff moisture

X(7) = Buildup Index

X(9) = 1/fine fuel moisture (0 to 1 cm)

X(10) = 1/needle moisture

X(11) = 1/average upper duff moisture content

X(14) = 1/X(5)

Table 9.--*Water-can weight loss as it varies with duff moisture and buildup index*

Buildup index	Upper duff moisture content (percent)[1]									
	10	20	30	40	50	60	70	80	90	100
	weight loss (grams)									
25	700	650	590	540	480	430	370	320	260	200
50	880	820	770	710	660	600	550	490	430	380
75	1,010	960	900	850	790	730	680	620	570	510
100	1,120	1,070	1,010	960	900	850	790	740	680	630
125	1,220	1,170	1,110	1,060	1,000	950	890	840	780	730
150	1,310	1,260	1,200	1,150	1,090	1,040	980	930	870	820
175	1,400	1,340	1,290	1,230	1,180	1,120	1,060	1,010	950	900
200	1,470	1,420	1,360	1,310	1,250	1,200	1,140	1,090	1,030	980
225	1,550	1,490	1,440	1,380	1,320	1,270	1,210	1,160	1,100	1,050

[1]/Approximate range of collected data is indicated by internal line.

A table of solutions for the equation over the range of its applicability is shown in table 9. Values near 1,000 grams characterize "hot" fires; lower values represent "cool" fires. Heat pulse to the site can be computed from the same input data as used to estimate duff reduction--upper duff moisture content and Buildup Index. In fact, our analysis showed a strong, positive correlation between water-can weight loss and duff consumption. As a result of this correlation, an intensive review of study data was undertaken and an effort made to develop a relationship between heat released per unit of area by burning of the slash fuels and the reduction in depth of duff observed on the site (Albini 1975). The effort failed.

Radiometer Measurements

An infrared radiometer, a device for measuring infrared radiation from a fixed area, was employed in this study. Typically, the radiometer was positioned on a hillside opposite the burn and focused on the center of the fire. The instrument read the average fire intensity over a 100 to 200 square meter area.

Ten fires were sufficiently documented to relate the radiometer data to water loss and duff reduction data. The data were analyzed to test if water-can weight loss and duff reduction, or both, are statistically related to radiometric infrared measurements.[4]

Table 10 provides the basis for a regression analysis between radiometric data and water-can weight loss or duff depth reduction, where:

Y(1) = time-temperature areas (°F - min)

Y(2) = time-voltage areas (volt - min)

X(1) = water-can weight loss (g)

X(2) = duff depth reduction (cm)

A regression program was run for each pair of functions. The resulting equations, along with the associated F and R^2 values are listed in table 11. Many more observations and further analysis will be required before definitive correlations can be attempted.

[4]Norum, Rodney A. Infrared radiation as a measure of relative fire intensity. Unpublished report on file at the Northern Forest Fire Laboratory, USDA Forest Service, Missoula, Montana.

Table 10.--*Relationship of radiometric data to duff loss and water loss data*

Unit	Time-temperature	Time-volts	Duff loss	Water loss
			Cm	*G*
N4	15163350E+07	0.54450000E+04	1.28	496.81
N6	0312500E+07	.30450000E+04	1.15	302.91
N8	11709750E+07	.20700000E+04	.37	266.33
N14	14958150E+07	.29985000E+04	1.00	125.89
N15	6247100E+07	.54225000E+04	.73	136.97
E10	3525800E+07	.70725000E+04	.67	415.14
W3	13762800E+07	.53625000E+04	.57	423.03
W4	20335500E+06	.43500000E+03	.01	52.53
W12	3442300E+07	.97650000E+04	1.02	555.83
W15	23245950E+07	.87600000E+04	.83	288.44

Table 11.--*Regression equation relating radiometer data to duff loss and water loss data*

Y	X	Regression equation	F	R^2
Time-temperature	Water loss	Y = 1,955.8 + 884,782X	3.13	0.28
Time-temperature	Duff loss	Y = 683,070 + 1,196,058X	1.14	.13
Time-volts	Water loss	Y = 12.11 + 1,327.7X	7.03	.47
Time-volts	Duff loss	Y = 3,648.8 + 2,253.6X	2.28	.22

Rate-of-Spread Measurements

Rate-of-spread is an essential parameter in Byram's equation (Davis 1959) for estimating fire intensity. Fire spread measurements were attempted by using thermocouple networks on 2-1/2-acre units (fig. 14) and an infrared line scanner. Although both attempts failed, results are reported to guide future researchers.

A multipen recorder registered the time fire reached each thermocouple. It also recorded, in millivolts, the temperature equivalent of the wires as that particular circuit was sequenced. Construction and installation of thermocouple networks was difficult and time consuming. After initial use, reliability of the thermocouples was poor, consequently their use was abandoned after a few fires.

An infrared line scanner equipped with an uncooled lead selenide detector was also tested for collecting rate-of-spread data. The system picks up infrared emissions through smoke and darkness. Photographic records of its cathode ray display tube and magnetic tape data storage permit reconstruction of the fire front. Data reduction was too laborious and costly for completion. For example, distortion resulting from an oblique viewing point must be adjusted mathematically or graphically after viewing geometry is measured. The data collected, when properly reduced, might prove useful in fire modeling, especially for model verification.

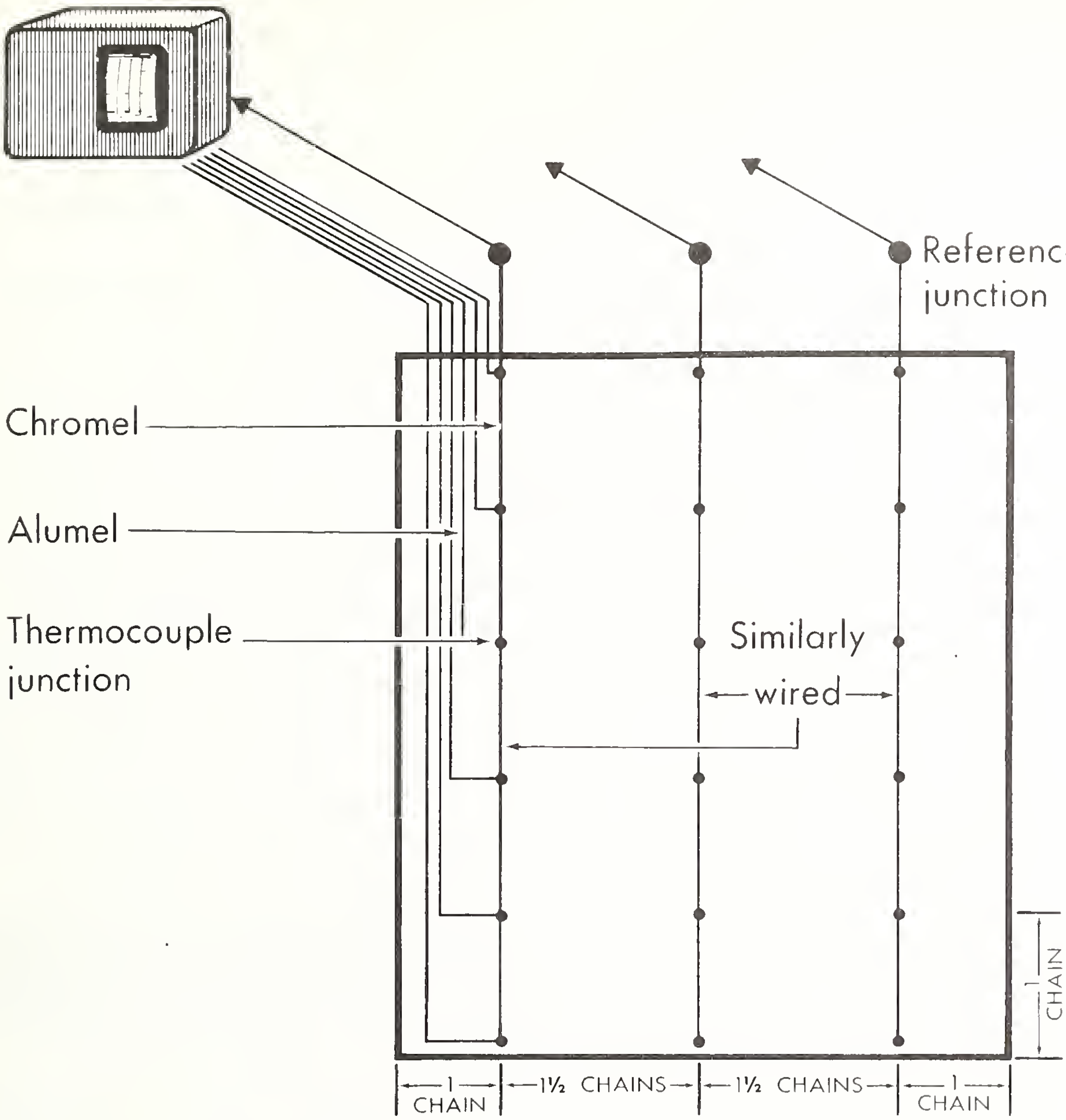

Figure 14.--Thermocouple network to measure rate of spread through 2-1/2-acre plot.

SUMMARY

This report provides a project record for the Miller Creek-Newman Ridge Study. The overall objective of this study was to develop criteria for scheduling prescribed fires to accomplish site preparation and hazard reduction needs. Results apply to broadcast burning of western larch/Douglas-fir clearcuts in western Montana.

The fuel complex resulting from clearcutting in larch/fir stands is characterized in this report. Fuel distribution and loading by size class is described for the four cardinal exposures. Range and frequency of occurrence of fuel moisture conditions is documented for a 3-year period and should be of value to managers writing hazard reduction plans and fire prescriptions for larch/fir clearcuts.

An equation is presented for predicting duff depth reduction from upper duff moisture content and Buildup Index. This equation, or the table of solutions, can assist managers in determining burning conditions required for adequate site preparation in conjunction with natural regeneration schemes.

Fuel reduction can be estimated from the 62 case studies of fuel loss presented herein. This information can be helpful in identifying burning conditions necessary to accomplish fuel management objectives.

Fifty-five fires were successfully ranked according to fire intensity. Consequently, the results of ancillary studies will be related to fire intensity, which will provide the forest manager with an increased capability to evaluate the environmental impact of planned prescribed fires in larch/fir stands.

Although the research findings reported here do not provide the often sought "magic formula" for prescribed burning, a manager can greatly increase the probability of a successful burn by considering these results when writing fire prescriptions.

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Steele, Robert W., and William R. Beaufait.
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1958. On the rate of burning of cribs of wood. Joint Fire Res. Organ. Boreham Wood, Herts, England. Fire Res. Note 370.

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1963. The size of flames from natural fires. *In* Ninth Int. Symp. Combust., p. 844-859. New York: Acad. Press.

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1965. Compartment prescription handbook. USDA For. Serv. Handb. 2411.14, Reg. 1. (Recently recatalogued 2409.21d.)

Van Wagner, C. E.
1965. Prescribed burning experiments red and white pine. Can. Dep. For. Publ. 1020, p. 27.

Wikstrom, J. H., and J. R. Alley.
1967. Cost control in timber growing on the national forests of the Northern Region. USDA For. Serv. Res. Pap. INT-42, p. 37. Intermt. For. and Range Exp. Stn., Ogden, Utah.

Weaver, Harold.
1955. Fire as an enemy, friend, and tool in forest management. J. For. 53:499-504.

Wellner, C. A.
1946. Recent trends in silvicultural practice on national forests in the western white pine type. J. For. 44:942-944.

Williams, D. E.
1958. Two control-burns in jack pine cut-over. For. Branch Pulp and Pap. Mag. Can., p. 5.

APPENDIX A: PUBLICATIONS— MILLER CREEK-NEWMAN RIDGE STUDY

Part I: Published Papers

Adams, Donald F., and Robert K. Koppe.
1969. The use of real time airborne instrumentation. Paper 69-AP-27. 12 p. Wash. State Univ., Pullman.

Airborne instrumentation was used to study smoke plumes from experimental prescribed burns conducted by the Northern Forest Fire Laboratory and Region 1 foresters. Burns were scheduled between May and November each summer to represent a variety of fuel moisture and meteorological conditions.

Flights were made through the smoke plumes with real time instrumentation to establish aerosol concentrations and size distribution, visual range, and carbon dioxide profiles. Flight patterns were selected to characterize plume transport and dispersion downwind under known meteorological conditions. Data demonstrate the utility of airborne real time instrumentation in air pollution research.

Adams, D. F., and R. K. Koppe.
1969. Instrumenting light aircraft for air pollution research. J. Air. Pollut. Control Assoc. 19(6):410-415.

The airborne instrumentation package described measures and records up to 27 pollutant and flight variables. Real-time analysis instrumentation include nondispersive infrared analyzers for CO_2, CO, and hydrocarbons, conductivity and coulometric analyzers for sulfur dioxide and sulfur-containing gases, and Charlson-Ahlquist visual range nephelometer. A Battelle "bulk sampler" is used to collect particulates. Air speed, altitude, rate of climb, magnetic heading, temperature, and relative humidity are continuously measured. All variables are recorded on magnetic tape. Tape data are reduced directly by IBM 360 computer to a digital printout or from tape to an X-Y analog plot.

Beaufait, William R.
1968. Scheduling prescribed fires to alter smoke production and dispersion. *In* Prescribed Burning and Management of Air Quality, Southwest Interagency Fire Counc. Proc. 1968:33-42.

The Northern Region-Intermountain Station cooperative study of the use of fire in silviculture is described. The author discusses data collection instrumentation, especially that associated with Washington State University's air pollution research group's activities. Some preliminary results indicate that convection columns rose to a higher altitude and smoke plumes were more greatly dispersed from Miller Creek burns when fuels were relatively dry and lapse rate was favorable than under the reverse conditions. To minimize smoke effects, fires should be scheduled when fuels are dry enough to create a strong convection column. Meteorological and fuel conditions required for adequate smoke dispersion can be made to correspond with those that achieve the beneficial goals of prescribing burning.

Beaufait, William R.
1971. Fire and smoke in Montana forests. *In* Land use and the Environment. Mont. For. and Range Exp. Stn. Sch. For. Univ. Mont., Missoula.

Beaufait, William R., and Owen P. Cramer.
1969. Prescribed fire smoke dispersion-principles. USDA For. Serv., In-Serv. Rep., 12 p. Missoula, Mont. (Rev. Jan. 1972)

An illustrated presentation of the principles that must be considered in developing prescribed burning guidelines and in successfully conducting prescribed fires that result in efficient smoke management.

Beaufait, William R., and William C. Fischer.
1969. Identifying weather suitable for prescribed burning. USDA For. Serv. Res. Note INT-94, 7 p. Intermt. For. and Range Exp. Stn., Ogden, Utah.

Fire managers required 24-hour records of temperature, relative humidity, and windspeed to use fire efficiently and effectively. When carefully calibrated and interpreted, modified hygrothermographs provide minimum instrumentation to obtain these records. An actual case of record interpretation and use is included.

Beaufait, William R., Michael A. Marsden, and Rodney A. Norum.
1974. Inventory of slash fuels using 3P subsampling. USDA For. Serv. Gen. Tech. Rep. INT-13, 17 p. Intermt. For. and Range Exp. Stn., Ogden, Utah.

The Northern Region-Intermountain Station cooperative studies of the use of fire in silviculture required the development of a system to inventory clearcut logging slash fuels, both before and after treatment, by broadcast fires of varying intensity. This paper describes the theory, sampling design, field procedures, and data processing programs for the inventory systems that were developed and applied on 100 2-1/2-acre plots. The method employed is a variation on the line transect technique which utilizes line intersect counts to compute fuel volume, weight, and surface area. The method and results should be of value to those who wish to quantify similar slash fuels.

Brown, James K.
1970. Vertical distribution of fuel in spruce-fir logging slash. USDA For. Serv. Res. Pap. INT-81, 9 p. Intermt. For. and Range Exp. Stn., Ogden, Utah.

About 70 percent of the volume and surface area of spruce-fir logging slash lies below the mid-depth of the slash. Material 0 to 1 centimeter in diameter was distributed vertically in the same proportions as all other material. Old slash in the first

20 centimeters above the ground contained a higher proportion of large material than new slash. Quantity of slash averaged 26.5 kg/m (118 tons/acre) dry weight with 0.57 kg/m composed of material 0 to 1 centimeter in diameter. Bulk density of slash decreased vertically and averaged 0.030 g/cc for new slash and 0.053 for old slash. Needle mats suspended in the slash occurred with a 40 percent frequency.

DeByle, Norbert V.
1973. Broadcast burning of logging residues and the water repellency of soils. Northwest Sci. 47:77-87.

Pertinent literature is reviewed and summarized. Water repellency of both organic and mineral soil horizons under larch and Douglas-fir were evaluated. Effects of prescribed broadcast burning on soil wettability are described.

DeByle, Norbert V., and Paul E. Packer
1972. Plant nutrient and soil losses in overland flow from burned forest clearcuts. Watersheds in Transition AWRA Symp. Proc., 296-307.

Describes the results of analyses of the overland flow and sediment from 24 runoff plots. Logging and burning temporarily impaired watershed protection and increased overland flow and erosion. However, vegetal recovery returned conditions to near prelogging status within four years. There was an increase in plant nutrient losses in both the sediment and in the overland flow during the denuded period; but it represented only a small fraction of the nutrient capital on these sites.

Fischer, William C., William R. Beaufait, and Rodney A. Norum.
1969. The hygrothermoaerograph--construction and fire management application. USDA For. Serv. Res. Note INT-87, 8 p. Intermt. For. and Range Exp. Stn., Ogden, Utah.

Conventional hygrothermographs can be modified to record windspeed along with temperature and relative humidity. The fire-weather record resulting from the modification has application in prescribed fire planning, fire-danger rating, fire-weather forecasting, fire behavior analysis, and fire-weather climatology.

Flaherty, David C.
1967. Better burns. . . and better air? Quest, Dec. 1967, p. 16-21, Wash. State Univ., Pullman.

This article, written in popular style, summarizes the objectives of the Miller Creek study and highlights the air pollution research of Washington State University.

Flaherty, David C.
1972. Are we objective about forest fires? Am. For. 78(9):12-15, 58-59.

A popular article concerning fire's role in the environment based on an interview with Dr. W. R. Beaufait. Beaufait explains why fire is a natural component of the northern Rocky Mountain forests. He describes how the Northern Region-Intermountain Station cooperative studies are contributing to a better understanding of the use of fire in silviculture.

Hardy, Charles E., and others.
1969. The Newman Ridge study. USDA For. Serv., Northern Reg. and Intermt. For. and Range Exp. Stn. 6 p.

A brochure describing the objectives and purpose of the Northern Region-Intermountain Station cooperative studies of the use of fire in silviculture. Deals with the history of the study, work being conducted on the Newman Ridge block, study design, instrumentation, and data-collection methods.

Koppe, Robert K.
1968. Forest fire smoke study. Quest Annu. Rep. 1968:12-13, Wash. State Univ., Pullman.

Koppe, Robert K., and Donald F. Adams.
1969. Dispersion of prescribed fire smoke. Pap. 69-AP-36, 21 p. Wash. State Univ., Pullman.

Describes smoke plumes resulting from prescribed burning of forest slash in the Miller Creek drainage, Flathead National Forest, near Kalispell, Mont. Results of airborne sampling for aerosol detection and for carbon dioxide analysis of two typical prescribed burns are described. Rate of plume spread was calculated for one burn as the plume was carried downwind by the winds aloft. The major portion of the plume was transported at 3,950 m at a rate between 14.8 and 20.9 m/sec. The average winds aloft speed was calculated to be 11.2 m/sec.

Simultaneous aerosol and carbon dioxide measurements show excellent correlation between smoke particles and increased carbon dioxide concentration for approximately 25 km downwind from prescribed burn plots. The carbon dioxide level in the diffusing plume was approximately 10 percent above background. From 25 to 55 km downwind the carbon dioxide concentration in the plume and the background were comparable, although the boundary of the plume was clearly discerned by the sampling instruments. Aerial intercepts of the edge of the convection column during the initial buildup phase of the fire revealed carbon dioxide concentrations up to 500 ppm.

Malte, P. C.
1974. Smoke production from forest slash burning: 1969 Montana fires at Newman Ridge. Internal Rep., Wash. State Univ., Pullman.

The percentage of slash fuel converted to smoke is presented for three of the 1969 Newman Ridge fires. Concentrations of particular matter and CO_2 were determined from airborne sampling devices, fuel inventories and moisture content data in conjunction with elemental analyses for C/H/N atom ratios, and burning table results.

Norum, Rodney A.
1974. Probable smoke column heights from slash fires. M.S. Thesis, 65 p. Univ. of Mont., Missoula.

Norum, Rodney A.
1974. Smoke column height related to fire intensity. USDA For. Serv., Res. Pap. INT-157, 7 p. Intermt. For. and Range Exp. Stn., Ogden, Utah.

The utlimate height of slash-fire smoke columns is shown to be strongly related to the character of the fire and only loosely related to lapse rate and other measures of atmospheric stability.

O'Dell, Clyde A.
1970. Analysis of USFS meteorological and WSU aircraft air quality data from western Montana. Prog. Rep., 16 p., Wash. State Univ., Pullman.

Describes an effort by the University of Washington and Washington State University to develop a first-approximation, large-scale diffusion model of forest fire smoke from the air quality data and meteorological observations obtained during Northern Region-Intermountain Station prescribed fire study. Anticipated yield would be prediction of smoke concentration downwind under various fuel conditions and loadings, atmospheric stability, and wind. The report describes the data available and difficulties incurred in analysis. It also gives summarized results of data analyzed.

Packer, Paul E.
1972. Site preparation in relation to environmental quality. *In* Proc. 1971 Annu. Meet. of West. For. and Conserv. Assoc. p. 23-28.

Summarizes the current knowledge about objectives and methods of site preparation for forest regeneration in relation to environmental quality. Discusses disposition of logging residue, reduction or elimination of plant competition, preparation of mineral soil seedbeds, and provision of favorable microenvironment. Covers the effect of prescribed fire, chemical treatment, and various mechanical methods of site preparation in relation to air and water pollution. Reviews new and needed development in site preparation.

Packer, Paul E.
1972. Effects of prescribed slash burning on watershed behavior of larch/Douglas-fir forest. Proc. XV IUFRO Congr., Univ. Florida, Gainesville.

Experiments in the Flathead National Forest in Montana showed that jammer logging changed surface soil properties and vegetative characteristics to enhance hydrology and soil stability. Prescribed burning proved to be detrimental to watershed in terms of runoff and soil erosion, but the effect only appears to last a few years. The soil erosion behavior of logged-burned units seems related more to the amount of protective groundcover and the climate than to other site factors.

Robinson, E.
1973. Dispersion of slash-burn smoke over forest areas. Pap. 73-AP-44, Coll. of Eng., Wash. State Univ., Pullman.

Robinson, Elmer, Donald F. Adams, and Robert K. Koope.
[n.d.] Dispersion of slash fire smoke plumes. Internal Rep., Wash. State Univ., Pullman.

Part II: Papers in Preparation

DeByle, Norbert V.
[n.d.] Soil fertility as affected by prescribed broadcast burning following clearcutting in northern Rocky Mountain larch/fir forests. *In* Proc. Fire and Land Manage. Symp., Oct. 8-10, 1974; Missoula, Mont., Tall Timbers Fire Res. Stn., and Intermt. Fire Res. Counc.

Plant nutrients and associated parameters were determined for soils under more than 40 monitored experimental burns of broadcast logging debris in western Montana. The duff or ash-duff mixture, and the 0 to 5, 5 to 10, 10 to 20, and 20 to 30 cm depths into mineral soil were sampled before, immediately after, and for up to 2 years after burning. Data are reported for pH, cation exchange capacity, and organic matter, total nitrogen, available and total phosphorus, exchangeable soluble and total potassium, sodium, calcium, and magnesium. Relationships of soil parameters to clearcutting and intensity of fire are discussed. Reports conclusions about effects of these treatments on the availability and supply of plant nutrients in medium to fine-textured soils derived from Belt series rocks.

Fiedler, Carl.
[n.d.] Wind movement in and around clearcuts, and possible seed dissemination implications. M.S., Sch. of For. Univ. Mont., Missoula.

Wind movement over two clearcuts of opposing aspect and the intervening ridge was studied. Three recording weather stations were used to gather continuous data on windspeed and direction. Supplemental data were obtained from a series of weather balloons on 100 foot lines, placed along the clearcut edges. Movement of these balloons with changing wind patterns was recorded by means of time lapse photography. Dispersal of smoke from smoke grenades was also photographed to aid in defining wind variation within units. Comparisons are made between wind behavior on opposite aspects and the ridgetop, and possible effects on seed dissemination are discussed.

Halvorson, Curtis H.
[n.d.] Effects of prescribed broadcast burning on small mammal populations in northern Rocky Mountain larch/fir forests. *In* Proc. Fire and Land Manage. Symp. Oct. 8-10, 1974; Missoula, Mont. Tall Timbers Fire Res. Stn., and Intermt. Fire Res. Counc.

Packer, Paul E.
[n.d.] Surface runoff and soil erosion as affected by prescribed broadcast burning following clearcutting in northern Rocky Mountain larch/fir forests. *In* Proc. Fire and Land Manage. Symp., Oct. 8-10, 1974; Missoula, Mont. Tall Timbers Fire Res. Stn., and Intermt. Fire Res. Counc.

Shearer, Raymond C.
1975. Seedbed characteristics in western larch forests after prescribed burning. USDA For. Serv. Res. Pap. INT-167, 26 p. Intermt. For. and Range Exp. Stn., Ogden, Utah.

Establishment of western larch seedlings is favored by site preparation that reduces the duff layer and sprouting of competing vegetation. A cooperative study of the use of fire in silviculture in northwestern Montana provided conditions to study the effectiveness of prescribed burning of logging slash for seedbed preparation from May through October. Greatest duff reduction, root mortality, and soil heating occurred when duff and soil water contents were lowest. Duff on north-facing slopes dries more slowly than on other aspects and the slash must be burned in the summer when the duff is dry to reduce the organic mantle and to prepare satisfactory seedbed. Summers of frequent rainfall may prevent satisfactory preparation of seedbeds on north slopes. East-, south-, and west-facing slopes have a wider range of time when burning will prepare seedbeds suitable for natural regeneration.

Shearer, Raymond C.
[n.d.] Establishment of conifers following prescribed broadcast burning in northern Rocky Mountain forests. *In* Proc. Fire and Land Manage. Symp., Oct. 8-10, 1974; Missoula, Mont., Tall Timbers Fire Res. Stn., and Intermt. Fire Res. Counc.

Regeneration of conifers following prescribed broadcast burning was studied on 40 clearcuts made in stands of western larch and associated species on north-, east-, south-, and west-facing slopes at two locations in western Montana. Natural regeneration success was more dependent on moisture gradients, as reflected by habitat types, than on the amount of mineral soil seedbed exposed by burning. The effect of prescribed burning on soil water, soil temperature, duff reduction, and mortality of nonconiferous roots is discussed. Seasonal fluctuations of seed crops, soil water, and soil temperature are related to seedling establishment.

APPENDIX B: DETAILED TREATMENT SCHEDULE

Burned by prescription								Not burned	Burned by wildfire				
Data used in analysis				Data held out				Control	Logged, unslashed			Standing timber	
Unit	Logged	Slashed	Burned	Unit	Logged	Slashed	Burned	unit	Unit	Logged	Burned	Unit	Burned
MILLER CREEK													
N4	8/67	10/67	8/31/68					N1					
N5	1/67	3/67	10/9/67					N2					
N6	8/67	10/67	9/10/68					N3					
N7	1/67	2/67	6/18/68					N10					
N8	1/68	2/68	9/10/68										
N9	7/67	9/67	7/26/68										
N11	2/67	3/67	8/3/67										
N12	2/67	3/67	8/3/67										
N13	7/67	7/67	7/8/68										
N14	1/68	2/68	10/3/68										
N15	1/68	2/68	10/3/68										
S1	6/67	6/67	5/18/68					S11	1/S14	10/66	8/67	2/S12	8/67
S2	12/67	2/68	5/18/68						1/S15	10/66	8/67	2/S13	
S3	7/67	2/68	5/18/68										
S4	12/67	2/68	7/3/68										
S5	10/67	11/68	9/30/68										
S6	7/67	8/67	8/23/67										
S7	5/67	5/67	8/23/67										
S8	4/67	5/67	8/8/67										
S9	2/67	6/67	10/5/67										
S10	2/67	5/67	7/3/68										
E1	7/67	7/67	10/10/67	3/E8	11/67	12/67	10/1/70	E2				2/E12	8/67
E3	10/67	11/67	8/7/68	3/E9	11/67	12/67	10/1/70						
E4	8/67	11/67	7/18/68										
E5	8/67	11/67	7/5/68										
E6	6/67	6/67	10/2/67										
E7	2/67	2/67	7/18/67										
E10	11/67	12/67	9/9/68										
E11	2/67	2/67	8/23/67										
E13	2/67	2/67	8/23/67										
E14	11/67	12/67	9/9/68										
E15	2/67	2/67	7/18/67										
W1	2/67	3/67	7/27/67									2/W6	8/67
W2	3/67	5/67	8/23/67										
W3	10/67	10/67	9/30/68										
W4	10/67	11/67	9/5/68										
W5	7/67	7/67	8/23/67										
W7	3/67	6/67	8/24/67										
W8	10/67	11/67	7/24/68										
W9	6/67	7/67	10/7/67										
W10	9/67	10/67	7/16/68										
W11	7/67	7/67	6/6/68										
W12	7/67	10/67	8/30/68										
W13	1/68	2/68	8/30/68										
W14	1/68	2/68	10/2/68										
W15	1/68	2/68	10/2/68										
NEWMAN RIDGE													
N1	8/68	9/68	7/14/69	3/N3	6/69	6/69	9/29/70	N4					
N2	8/68	6/69	7/25/69										
S1	7/68	7/68	6/4/69	3/S3	6/69	6/69	9/15/70	S4					
S2	9/68	11/68	7/16/69										
E1	7/68	8/68	7/9/69						E4	7/69	7/69		
E2	11/68	6/69	7/25/69										
E3	6/69	6/69	7/25/69										
W1	8/68	8/68	6/1/69	4/W3	11/68	6/69	9/28/70						
W2	9/68	11/68	7/18/69	4/W4	7/69	8/69	9/29/70						

1/ Subsequently machine piled and burned.

2/ Unsalvaged, special study unit.

3/ Burned 3 years after harvest, subject to special study.

4/ Burned 2 years after harvest, subject to special study.

APPENDIX C: PREBURN MOISTURE CONTENTS

Table 12.--*Average preburn moisture content of fuel components by block and unit*

Unit	Burn date	Duff: Lower 1/2	Duff: Upper 1/2	Litter	Slash: Needles	Slash: Branchwood 0-1 cm	Slash: Branchwood 1-10 cm
		Percent					
			MILLER CREEK				
N-4	8-31-68	99+	67	25	10	14	16
N-5	10-9-67	99+	85	48	6	15	37
N-6	9-10-68	99+	81	35	23	15	20
N-7	6-18-68	99+	45	10	18	12	37
N-8	9-10-68	99+	81	35	23	15	20
N-9	7-26-68	76	67	8	7	10	17
N-11	8-3-67	51	34	6	5	7	25
N-12	8-3-67	51	34	6	5	7	25
N-13	7-8-68	99+	95	13	7	13	17
N-14	10-3-68	99+	97	26	19	26	27
N-15	10-3-68	99+	97	26	19	26	27
E-1	10-10-67	90	99+	36	10	32	16
E-3	8-7-68	85	54	9	6	21	26
E-4	7-18-68	99+	77	15	12	17	38
E-5	7-5-68	99+	76	5	6	12	20
E-6	10-2-67	70	94	26	13	15	15
E-7	7-18-67	54	48	5	23	17	28
E-10	9-9-68	99+	55	23	13	15	17
E-13	8-23-67	56	24	5	4	6	18
E-14	9-9-68	99+	55	23	10	15	17
E-15	7-18-67	54	48	5	23	17	28
S-1	5-18-68	99+	28	6	8	11	21
S-2	5-18-68	99+	28	6	8	11	21
S-3	5-18-68	99+	28	6	8	11	21
S-4	7-3-68	99+	71	7	6	9	18
S-5	9-30-68	99+	65	20	18	20	35
S-7	8-23-67	56	24	5	4	6	18
S-8	8-8-67	28	43	7	24	19	22
S-9	10-5-67	77	99+	68	10	15	13
S-10	7-3-68	99+	71	7	6	9	18
W-1	7-27-67	94	47	4	16	12	19
W-2	8-23-67	56	24	5	4	6	18
W-3	9-30-68	99+	65	20	18	20	35
W-4	9-5-68	99+	99+	32	12	18	29
W-5	10-9-67	56	24	5	4	6	18
W-7	8-24-67	56	24	5	4	6	18
W-8	7-24-68	63	85	16	8	14	33
W-9	10-7-67	52	89	34	11	17	17
W-10	7-16-68	78	41	9	6	7	9
W-11	6-6-68	99+	99+	38	9	12	19
W-12	8-30-68	99+	84	50	18	17	22
W-13	8-30-68	99+	84	50	18	17	22
W-14	10-2-68	99+	97	27	15	17	24
W-15	10-2-68	99+	97	27	15	17	24
			NEWMAN RIDGE				
N-1	7-14-69	54	17	9	6	10	11
N-2	7-25-69	63	16	8	8	13	7
E-1	7-9-69	45	13	6	9	11	13
E-2	7-25-69	63	16	8	8	13	7
E-3	7-25-69	63	16	8	8	13	7
S-1	6-4-69	52	8	5	8	5	13
S-2	7-16-69	72	34	10	5	8	22
W-1	6-1-69	68	21	6	13	11	24
W-2	7-18-69	40	20	9	5	8	11

Table 13.--*Average preburn moisture content of fuel components by time of year*

Time period & burn date	Unit exposure	Duff: Lower 1/2	Duff: Upper 1/2	Litter	Slash: Needles	Slash: Branchwood 0-1 cm	Slash: Branchwood 1-10 cm	Unit average
		Percent						
May 16-31								
5-18-68	S	99+	28	6	8	11	21	29
Jun 1-15								
6-6-68	W	99+	99+	38	9	12	19	46
6-1-69	S	68	21	6	13	11	24	24
6-4-69	W	52	8	5	8	5	13	15
Jun 16-30								
6-18-68	N	99+	45	10	18	12	37	37
Jul 1-15								
7-3-68	S	99+	71	7	6	9	18	35
7-5-68	E	99+	76	5	6	12	20	36
7-8-68	N	99+	95	13	7	13	17	41
7-9-69	E	45	13	6	9	11	13	16
7-14-69	N	54	17	9	6	10	11	18
Jul 16-31								
7-18-67	E	54	48	5	23	17	28	29
7-27-67	W	94	47	4	16	12	19	32
7-16-68	W	78	41	9	6	7	9	25
7-18-68	E	99+	77	15	12	17	38	43
7-24-68	W	63	85	16	8	4	33	35
7-26-68	N	76	67	8	7	10	17	31
7-16-69	S	72	34	10	5	8	22	25
7-18-69	W	40	20	9	5	8	11	15
7-25-69	N&E	63	16	8	8	13	7	19
Aug 1-15								
8-3-67	N	51	34	6	5	7	25	21
8-8-67	S	28	43	7	24	19	22	24
8-7-68	E	85	54	9	6	21	26	34
Aug 16-31								
8-23-67	E,S&W	56	24	5	4	6	18	19
8-24-67	W	56	24	5	4	6	18	19
8-30-68	W	99+	84	50	18	17	22	48
8-31-68	W	99+	67	25	10	14	16	39
Sep 1-15								
9-5-68	W	99+	99+	32	12	18	29	48
9-9-68	E	99+	55	23	13	15	17	37
9-10-68	N	99+	81	35	23	15	20	46
Sep 16-30								
9-30-68	S&W	99+	65	20	18	20	35	43
Oct 1-15								
10-2-67	E	70	94	26	13	15	15	39
10-5-67	S	77	99+	68	10	15	13	47
10-7-67	W	52	89	34	11	17	17	37
10-9-67	N	99+	85	48	6	15	37	48
10-9-67	W	56	24	5	4	6	18	19
10-10-67	E	90	99+	36	10	32	16	47
10-2-68	E	99+	97	27	15	17	24	47
10-3-68	N	99+	97	26	19	26	27	49

APPENDIX D: WEATHER SUMMARIES

Part I: Miller Creek, 1967

	Date															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
JUNE																
Precipitation (inches)	--	0.02	0.59	0.11	--	--	0.50	0.18	0.25	0.08	--	0.03	--	--	--	0.03
Minimum humidity (percent)	46	34	80	47	22	34	41	60	73	56	37	52	38	27	27	35
Maximum temperature (°F)	70	59	43	54	66	62	66	56	55	54	56	52	60	71	74	77
Fine fuel moisture	19	17	18	9	5	6	8	11	14	10	8	10	6	4	4	6
Buildup Index	32	34	16	18	21	24	17	11	11	12	14	16	19	23	27	30

	Date														
	17	18	19	20	21	22	23	24	25	26	27	28	29	30	Total
JUNE															
Precipitation (inches)	--	0.37	--	--	1.25	0.50	--	--	--	--	--	--	--	--	3.91
Minimum humidity (percent)	38	58	33	28	29	70	38	54	40	29	48	30	16	22	
Maximum temperature (°F)	72	63	73	78	77	61	60	58	68	74	67	72	72	70	
Fine fuel moisture	6	9	5	4	19	30+	19	27	19	16	18	15	14	14	
Buildup Index	33	23	26	30	6	5 [1]	17	17	19	22	24	27	31	35	

	Date															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
JULY																
Precipitation (inches)	--	--	--	--	0.02	--	--	0.04	--	--	--	--	--	--	--	--
Minimum humidity (percent)	27	31	33	25	28	24	30	32	28	28	31	25	33	16	23	18
Maximum temperature (°F)	72	78	81	76	73	74	71	69	64	71	78	85	88	80	78	83
Fine fuel moisture	15	15	16	15	15	10	13	9	8	5	5	4	5	4	4	4
Buildup Index	38	41	44	47	50	53	56	58	60	63	66	70	73	78	82	86

	Date															
	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	Total
JULY																
Precipitation (inches)	T	--	--	--	0.01	--	--	--	--	--	--	--	--	--	--	07
Minimum humidity (percent)	24	18	35	43	31	32	19	23	24	22	25	13	13	24	38	
Maximum temperature (°F)	70	75	73	77	70	72	77	82	78	80	82	86	80	78	73	
Fine fuel moisture	10	4	4	8	5	5	4	4	6	6	6	6	3	5	5	
Buildup Index	87	90	93	95	98	101	105	109	112	115	118	121	126	130	133	

	Date															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
								AUGUST								
Precipitation (inches)	--	--	--	--	--	--	0.01	--	--	--	--	--	--	--	--	--
Minimum humidity (percent)	19	18	24	20	14	30	50	33	30	22	25	22	13	13	18	18
Maximum temperature (°F)	74	79	82	86	81	76	63	71	77	85	85	86	86	86	87	87
Fine fuel moisture	4	4	4	4	3	5	8	6	5	4	4	4	2	2	3	3
Buildup Index	137	142	146	151	156	159	161	164	167	172	176	181	188	195	200	205

	Date															
	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	Total
								AUGUST								
Precipitation (inches)	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	.01
Minimum humidity (percent)	13	13	17	16	26	19	20	--	21	--	--	36	--	--	16	
Maximum temperature (°F)	90	89	89	87	77	79	80	--	73	80	78	77	86	86	85	
Fine fuel moisture	3	2	3	3	5	4	4	4	4	4	6	6	4	4	3	
Buildup Index	210	217	222	227	230	235	239	243	247	251	255	258	262	266	271	

	Date															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
								SEPTEMBER								
Precipitation (inches)	--	--	--	--	T	--	--	--	--	0.30	--	--	--	--	--	--
Minimum humidity (percent)	10	38	34	23	21	30	32	23	29	14	64	30	23	22	22	22
Maximum temperature (°F)	90	69	78	85	90	72	80	79	78	74	51	57	66	74	77	75
Fine fuel moisture	2	6	6	4	4	5	4	5	4	6	18	7	6	4	4	4
Buildup Index	278	281	284	288	292	295	299	302	307	310	310	312	315	319	323	327

	Date														
	17	18	19	20	21	22	23	24	25	26	27	28	29	30	Total
							SEPTEMBER								
Precipitation (inches)	--	--	--	--	--	--	--	--	--	--	--	--	--	--	.30
Minimum humidity (percent)	22	28	32	25	21	14	14	14	20	28	28	13	26	38	
Maximum temperature (°F)	70	72	76	79	83	68	71	77	73	69	74	82	75	56	
Fine fuel moisture	4	4	6	4	4	4	3	4	4	6	4	2	6	8	
Buildup Index	331	335	338	342	347	351	356	361	365	368	372	379	382	384	

	Date															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
								OCTOBER								
Precipitation (inches)	--	0.21	0.21	--	--	--	--	--	--	--	0.21	0.14	0.25	0.10	--	--
Minimum humidity (percent)	75	46	74	34	30	62	50	25	35	40	68	48	76	80	70	31
Maximum temperature (°F)	44	46	41	52	53	46	49	66	65	63	58	47	39	44	45	56
Fine fuel moisture	30+	10	18	9	9	14	14	6	6	8	25	10	30+	18	21	7
Buildup Index	384	116	69	71	73	74	75	78	81	83	58	51	42	42	42	44

1/ Adjusted for missing data.

	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	Total
	OCTOBER															
Precipitation (inches)	--	--	0.30	--	T	--	0.24	--	0.20	--	0.72	--	--	--	0.05	2.63
Minimum humidity (percent)	53	37	48	42	29	62	67	61	62	43	48	54	50	61	50	
Maximum temperature (°F)	55	57	43	50	49	40	40	49	40	41	40	44	39	38	54	
Fine fuel moisture	10	10	12	8	30+	30+	14	25	16	10	30	25	16	30	30	
Buildup Index	46	47	38	40	40	40	31	31	31	32	12	12	12	12	12	

Part II: Miller Creek, 1968

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
	JUNE															
Precipitation (inches)	--	--	0.14	--	--	0.02	0.32	0.09	--	--	0.56	--	--	0.70	0.10	--
Minimum humidity (percent)	43	49	34	41	36	51	81	54	56	56	56	32	50	74	66	31
Maximum temperature (°F)	62	62	58	61	67	57	54	61	61	64	64	57	50	48	52	67
Fine fuel moisture	14	23	18	19	17	23	30+	19	24	22	19	18	24	30+	25	16
Buildup Index	12	13	12	14	16	17	12	14	15	16	11	13	14	6	7	10

	17	18	19	20	21	22	23	24	25	26	27	28	29	30	Total
	JUNE														
Precipitation (inches)	--	--	--	--	--	0.18	0.19	--	--	--	0.07	0.07	0.20	0.41	3.05
Minimum humidity (percent)	33	30	--	--	--	--	--	--	--	10	28	40	82	96	
Maximum temperature (°F)	66	74	--	--	--	--	--	--	--	80	67	52	44	49	
Fine fuel moisture	17	16	16	18	17	30+	30+	20	19	13	18	20	30+	30+	
Buildup Index	12	15	18	20	18	16	16	17	19	24	26	27	26	18	

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
	JULY															
Precipitation (inches)	--	--	--	--	--	--	--	0.01	--	--	0.01	0.06	--	--	--	--
Minimum humidity (percent)	32	32	20	20	22	26	16	34	26	28	34	52	30	40	51	32
Maximum temperature (°F)	64	74	81	85	85	84	88	84	86	79	81	67	63	63	61	68
Fine fuel moisture	13	10	9	8	9	12	8	10	9	10	11	19	11	13	15	12
Buildup Index	20	23	27	32	36	38	43	46	50	54	57	58	61	63	64	66

	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	Total
	JULY															
Precipitation (inches)	--	--	--	0.28	--	--	--	--	--	--	--	--	--	--	--	.36
Minimum humidity (percent)	38	36	26	60	38	30	46	26	24	24	24	24	24	42	38	
Maximum temperature (°F)	63	68	77	54	66	70	66	73	77	80	83	84	76	64	71	
Fine fuel moisture	12	13	10	16	13	11	15	11	10	10	10	10	10	13	11	
Buildup Index	68	70	74	55	57	60	61	64	67	70	74	78	82	84	87	

	Date															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
AUGUST																
Precipitation (inches)	--	--	--	--	--	--	--	--	--	--	0.11	--	--	0.48	0.60	0.17
Minimum humidity (percent)	24	24	34	23	26	33	20	18	17	54	22	22	28	24	99	66
Maximum temperature (°F)	81	84	82	78	75	73	76	79	79	69	73	69	70	73	54	56
Fine fuel moisture	4	4	5	4	4	5	4	4	8	10	5	6	5	30+	30+	13
Buildup Index	91	95	98	102	106	109	114	119	121	122	109	112	115	50	22	22

	Date															
	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	Total
AUGUST																
Precipitation (inches)	0.03	--	--	0.12	0.36	--	--	--	--	--	--	0.07	0.05	--	--	1.99
Minimum humidity (percent)	53	46	42	62	65	45	46	48	30	25	49	60	70	39	40	
Maximum temperature (°F)	58	59	58	55	58	55	55	67	72	73	63	59	60	70	72	
Fine fuel moisture	22	9	14	15	18	9	15	8	5	8	8	22	11	6	6	
Buildup Index	22	24	25	22	12	14	15	17	20	22	24	24	25	28	31	

	Date															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
SEPTEMBER																
Precipitation (inches)	--	0.50	0.50	0.02	--	0.15	--	--	--	--	--	0.09	--	0.36	0.15	0.13
Minimum humidity (percent)	40	47	65	53	68	28	30	30	35	37	37	41	41	57	62	46
Maximum temperature (°F)	72	63	54	58	58	70	68	66	71	76	77	74	62	60	52	52
Fine fuel moisture	9	10	30+	10	15	6	6	8	6	6	6	8	10	30+	14	10
Buildup Index	33	23	15	17	18	19	22	24	27	30	33	35	36	23	22	23

	Date														
	17	18	19	20	21	22	23	24	25	26	27	28	29	30	Total
SEPTEMBER															
Precipitation (inches)	0.18	0.75	0.05	--	0.10	0.50	0.03	0.17	--	--	0.06	--	--	--	3.74
Minimum humidity (percent)	60	62	49	53	76	89	50	54	40	42	52	62	55	42	
Maximum temperature (°F)	52	46	47	46	38	42	54	55	63	64	62	56	61	62	
Fine fuel moisture	11	25	10	19	30+	30+	10	15	8	10	30+	11	9	10	
Buildup Index	22	9	11	11	11	8	10	11	13	14	14	15	17	18	

	Date										
	1	2	3	4	5	6	7	8	9	10	Total
OCTOBER											
Precipitation (inches)	--	--	--	0.10	--	0.07	0.03	--	--	0.10	.30
Minimum humidity (percent)	35	36	30	31	47	49	59	39	44	45	
Maximum temperature (°F)	60	52	51	51	47	43	42	41	43	43	
Fine fuel moisture	9	8	8	25	10	18	21	9	13	14	
Buildup Index	20	22	24	24	25	25	25	27	28	29	

Part III: Newman Ridge, 1969

JUNE

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Precipitation (inches)	--	--	--	--	--	0.05	--	--	--	--	0.15	--	--	--	--	--
Minimum humidity (percent)	28	34	30	23	40	56	58	40	45	31	24	86	30	21	24	21
Maximum temperature (°F)	68	72	78	85	73	71	63	71	72	66	74	46	59	67	69	71
Fine fuel moisture	16	16	15	13	18	30+	20	16	18	16	15	30+	17	15	16	15
Buildup Index	18	21	24	29	31	31	33	36	38	41	43	43	45	48	51	54

JUNE

	17	18	19	20	21	22	23	24	25	26	27	28	29	30	Total
Precipitation (inches)	--	--	0.10	--	0.05	0.21	0.51	0.16	0.19	0.09	0.09	0.01	0.02	--	1.63
Minimum humidity (percent)	25	28	32	46	61	62	72	74	66	84	60	58	70	28	
Maximum temperature (°F)	75	79	78	70	59	55	55	46	44	44	52	50	53	65	
Fine fuel moisture	15	15	15	19	24	21	24	28	30+	30+	24	23	25	16	
Buildup Index	57	60	63	65	66	49	23	21	21	21	22	23	24	27	

JULY

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Precipitation (inches)	--	--	0.23	--	--	--	0.07	--	--	--	--	--	--	--	--	--
Minimum humidity (percent)	26	43	65	45	58	34	40	37	28	30	37	45	26	36	30	27
Maximum temperature (°F)	73	71	50	59	57	64	65	66	75	78	64	60	66	65	68	72
Fine fuel moisture	14	19	22	15	16	11	16	13	10	10	15	15	11	13	11	10
Buildup Index	31	33	26	27	28	31	32	34	38	42	43	44	47	49	52	56

JULY

	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	Total
Precipitation (inches)	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	.30
Minimum humidity (percent)	30	26	20	29	29	30	30	36	36	40	30	18	20	16	20	
Maximum temperature (°F)	74	76	81	80	77	76	81	78	79	65	74	80	76	82	80	
Fine fuel moisture	10	10	8	10	10	10	10	11	11	13	10	8	10	8	9	
Buildup Index	59	63	68	72	75	78	82	85	88	90	93	98	102	107	111	

AUGUST

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Precipitation (inches)	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Minimum humidity (percent)	20	20	16	22	33	28	20	26	20	28	26	43	28	24	34	30
Maximum temperature (°F)	82	83	78	80	57	70	76	76	81	82	80	62	75	82	78	63
Fine fuel moisture	8	8	8	9	12	10	11	10	8	9	10	13	10	8	10	11
Buildup Index	116	121	126	130	132	136	139	143	148	152	156	158	161	166	169	172

	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	Total
AUGUST																
Precipitation (inches)	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	.00
Minimum humidity (percent)	22	31	37	24	32	15	16	19	28	20	37	48	30	31	27	
Maximum temperature (°F)	74	70	70	74	88	92	96	91	72	79	65	86	68	70	75	
Fine fuel moisture	10	10	11	10	3	3	2	3	3	4	6	6	6	6	4	
Buildup Index	176	179	182	186	191	196	201	206	209	213	216	219	222	225	229	

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
SEPTEMBER																
Precipitation (inches)	--	--	--	--	--	--	--	--	--	--	--	--	0.09	--	--	--
Minimum humidity (percent)	22	29	46	74	40	25	22	28	24	26	36	38	46	39	21	26
Maximum temperature (°F)	84	78	51	43	57	71	81	78	81	82	81	80	64	54	60	69
Fine fuel moisture	4	5	10	17	8	6	4	5	5	6	6	6	11	8	5	6
Buildup Index	234	237	238	238	240	243	248	251	253	256	259	262	263	265	268	271

	17	18	19	20	21	22	23	24	25	26	27	28	29	30	Total
SEPTEMBER															
Precipitation (inches)	--	0.10	0.03	0.22	0.02	--	0.42	0.11	0.02	--	0.06	--	0.06	0.65	1.78
Minimum humidity (percent)	30	40	70	74	67	46	45	62	54	42	41	51	36	58	
Maximum temperature (°F)	74	60	55	48	53	57	51	51	53	59	63	63	65	47	
Fine fuel moisture	5	11	21	21	15	10	15	17	10	10	10	10	8	25	
Buildup Index	274	275	155	86	87	88	44	44	45	46	47	48	50	22	

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
OCTOBER																
Precipitation (inches)	0.32	--	0.04	--	--	--	--	0.20	0.10	--	--	--	--	--	--	--
Minimum humidity (percent)	60	65	56	40	52	60	30	74	74	81	44	43	41	37	43	43
Maximum temperature (°F)	49	42	46	48	44	49	57	55	40	38	40	34	37	43	45	44
Fine fuel moisture	30	15	17	10	12	15	9	21	30	25	11	11	10	8	9	10
Buildup Index	15	16	16	18	19	20	22	21	21	21	22	23	24	26	28	29

	17	18	19	20	21	22	23	24	25	26	27	28	Total
OCTOBER													
Precipitation (inches)	--	--	--	--	--	--	0.29	0.25	--	--	0.05	0.08	1.33
Minimum humidity (percent)	38	31	40	60	40	29	45	67	75	66	70	65	
Maximum temperature (°F)	50	50	47	50	64	67	56	44	37	40	38	48	
Fine fuel moisture	9	8	10	13	8	6	15	30	19	21	25	23	
Buildup Index	31	33	35	36	38	41	35	26	26	26	26	26	

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1975. Broadcast burning in larch-fir clearcuts: the Miller Creek-Newman Ridge study. USDA For. Serv. Res. Pap. INT-175, 53 p. (Intermountain Forest and Range Experiment Station, Ogden, Utah 84401.)

Describes a major study of broadcast burning for hazard reduction and site preparation in western Montana larch-fir clearcuts and the effects of such prescribed fires on soil, air, water, wildlife, and tree regeneration. The study area is described and prefire fuel conditions documented. Results of attempts to quantitatively evaluate the experimental burns in terms of duff reduction and fuel loss as well as attempts to characterize fires according to relative intensity are provided.

OXFORD: 432.16; 435.
KEYWORDS: fuel reduction, fire effects, prescribed fire, broadcast burning, site preparation, fire intensity, fuel management.

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OXFORD: 432.16; 435.
KEYWORDS: fuel reduction, fire effects, prescribed fire, broadcast burning, site preparation, fire intensity, fuel management.

Headquarters for the Intermountain Forest and Range Experiment Station are in Ogden, Utah. Field programs and research work units are maintained in:

- Billings, Montana
- Boise, Idaho
- Bozeman, Montana (in cooperation with Montana State University)
- Logan, Utah (in cooperation with Utah State University)
- Missoula, Montana (in cooperation with University of Montana)
- Moscow, Idaho (in cooperation with the University of Idaho)
- Provo, Utah (in cooperation with Brigham Young University)
- Reno, Nevada (in cooperation with the University of Nevada)

AMERICAN REVOLUTION BICENTENNIAL
1776-1976

GROWING FROM '76
U.S. FORESTRY CENTENNIAL